PHYSICS education

Volume 17 1982

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EDITORIAL

Benighted education

ERIC DEESON, *Honorary Editor*

Unparalleled in the history of publishing (I'm sure that's untrue, but it's a good start) is The Institute of Physics' aid to benighted education by cutting the price of this magazine to members of the ASE, The Institute of Physics, and similar bodies. A nearly 15% cut in the subscription rate is not an easy step to take. Agreed, it accompanies an even bigger cut in the number of pages (well, do *you* have time to read it all?)—but it also accompanies rises in paper costs, postage, office overheads and so on.

If you are an individual subscriber reading this, I hope you appreciate what we have done for your bank manager's ulcers. Can you reciprocate by encouraging less enlightened colleagues to join us? You would also help by telling us what you like and dislike about the magazine; by contributing ideas, comments, news items; by sharing your physics teaching experience with us. If you are not an individual subscriber, should you be?

'Benighted education' was not at all meant to be a journalistic cliché. A year ago, when I wrote my first editorial for *Physics Education* (1981 **16** 1), I included some sad comments on the ever tougher economics of science education. I did not expect the situation to deteriorate as much as it has. I crudely estimated that we then had to get by on two-thirds of the resources of the mid-1960s. Now I reckon the figure is dropping towards half.

In 1981 we saw unimaginable economies—cuts in provision, larger classes, closure of departments, teachers out of work. In a recent copy of *The Guardian* there was a report of a school without enough paper to set the winter examinations. Its head talked of having the telephone taken out. My school is not much better off. My own department is halving its internal examinations, issuing textbooks only to A-level candidates (and they must share), feeding the mice to the snakes.

Britain's beloved string and sealing-wax days are here again. And again we shall succeed despite the difficulties. Should we fill the cheaper *Physics Education* with details of cheaper experiments?

Happy New Year? Hm.

NEWS AND COMMENT

ENERGY EDUCATION

With rising fuel costs, diminishing resources and a lot of scope for conservation, the broad subject of energy should be a part of everyone's education. Energy topics appear in a wide variety of school subjects, but few pupils will obtain an education in energy appropriate to their needs as future citizens and householders. Furthermore, girls are disadvantaged in their energy education since few girls study the subject which gives the greatest coverage of energy—physics. A more balanced treatment is called for by the Electricity Consumers' Council in a recent report by Valerie Richardson of an investigation into energy education in secondary schools.

The investigation included a computer analysis of over ninety subject syllabuses at CSE, CEE, O-, A- and AO-level from all examining boards in England and Wales. Energy education keywords (e.g. 'heat', 'electric current', 'cooker') were counted in the syllabuses and put into five categories (topics relevant to household energy education necessary for all, to a high level of 'energy literacy', to technicians, to scientists/engineers, and equations indicating 'energy numeracy' required by scientists or engineers). The results showed a wide range in the number of energy topics covered in different syllabuses: O-level syllabuses included, at one end, 228 different energy topics, and at the other end 139 topics. The ranges at other levels were 135–235 at A-level, 31–123 at OA level and 265–981 at CSE. In both the GCE and CSE syllabuses physics contained the largest number of energy topics, followed in GCE subjects by integrated science, physical science, chemistry, engineering, general science and home economics; and followed in CSE subjects by general science, chemistry, engineering and home economics. The relatively low frequency of energy topics in home economics is criticised by the Council, which calls for 'a reappraisal of the subject in view of the present world energy situation'.

At the same time, the Council notes, energy often comes into physical science subjects through topics such as magnets, forces, waves or motion 'which give pupils the academic ability to solve energy problems in their future employment but are not always valid for future citizens and householders in a world where the efficient utilisation of energy is of the utmost importance'. The Council does not feel that there

would be a great demand from pupils or parents for a separate course on energy studies, but calls instead for greater coordination between different subjects, ideally forming an integrated approach with contributions from a multiplicity of subjects such as science, geography, sociology and home economics.

Reviewing the resource material produced by government departments, industry, commercial organisations, consumer organisations, etc, the Council notes that much of the material is produced as part of publicity campaigns or promotion schemes. While topics such as energy supply are very well covered by industry-produced material, topics such as conservation are mostly covered by organisations which are on a more limited budget. More pupil-orientated material, specially produced for schools, is called for by the Council.

An Investigation into Energy Education in Secondary Schools by Valerie Richardson is available from the Electricity Consumers' Council, 119 Marylebone Road, London NW1 5PY, price £3.

SHORTAGE OF TEACHERS

The shortage of trained physics, chemistry and mathematics teachers has led the Government to introduce a two-year pilot scheme of teacher training scholarships. The £500 scholarships will be linked to one-year postgraduate teacher training courses followed by guaranteed jobs in England and Wales, and 70 scholarships will be offered in 1982–3, the first year of the scheme.

The move follows the widespread concern which has been voiced within the profession. Last year a Royal Society/Institute of Physics report estimated that there were 300 vacancies for physics teachers and that a further 1500 physics teaching posts were currently filled by people not fully qualified to teach physics (*Phys. Educ.* 1981 **16** 194).

The scholarships will be funded by the Department of Education and Science and the Welsh office, and the training courses will be held at eight institutions: Chelsea College Centre for Science and Mathematics Education, London; Homerton College, Cambridge; School of Education, University of Leeds; St Martin's College, Lancaster; Department of Education, University of Southampton; School of Education, Trent Polytechnic; University College of Wales, Aberystwyth; and University College, Cardiff.

Candidates are expected to have at least an upper second class honours degree in mathematics, physics or chemistry, although qualifications in related subjects will be considered. Final year undergraduates may also apply. The successful candidates will be selected by the DES and the Welsh Office in consultation with the teacher training institutions.

The application date for 1982–3 scholarships has already passed, but details of the scheme and the 1983–4 scholarships may be obtained from National Scholarships for Priority Teachers, Department of Education and Science, Elizabeth House, York Road, London SE1 7PH; or, for Wales, Further Education Division (1), Welsh Office, Cathays Park, Cardiff CF1 3NQ.

SINCLAIR ZX81

ERIC DEESON

Several readers have mentioned problems with the ZX81 'Projectile' program published in the September issue (*Phys. Educ.* 1981 **16** 295). We apologise for the following errors.

12 PAUSE 150 should be followed by POKE 16437,255 if the program is used with the ZX80 8K.

21 should have Y < = 0 not 1.

27, 28, 29 should be reordered to give FAST at the end.

Also the display can be improved by replacing YM in line 26 with INT(100*YM)/100, giving two decimal place accuracy.

Thus is progress made in educational computing. Our thanks to those who raised the queries!

MPEMBA COMES ALIVE

Over ten years ago a Tanzanian secondary-school student, Erasto Mpemba, noticed that water at 100°C froze quicker than an equal volume of water at 35°C. He put the observation to Denis Osborne, a physicist then working in Tanzania, and they subsequently wrote an article which was published in *Physics Education* in 1969 (reprinted in *Phys. Educ.* 1979 **14** 410–3). Letters to the magazine subsequently showed that the phenomenon was known to Descartes, Bacon and even Aristotle, and a number of experimenters have sought explanations in terms of loss of mass due to evaporation, convection currents, and air or CO_2 in the water, amongst other factors.

A recent note in *Innovation* (a montly report on industrial research and development and science based industry in Israel) suggests another possible factor: 'Tel Aviv University researchers have isolated bacteria which induce the formation of ice crystals at relatively moderate temperatures'. With so much interest in biotechnology currently, perhaps there is scope for a school project involving biology and physics departments? And to show that the phenomenon is more than just a quick way to make ice cream, *Innovation* adds 'Ultimately this research may lead to replacement of silver iodide in cloud seeding operations'.

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LETTERS

NUCLEAR DEBATE

In their contribution to the 'nuclear debate' in the September issue of *Physics Education* (1981 **16** 274–81), H I Ellington and E Addinall seem to prefer the arguments that are now familiar to readers of the glossy publications of the CEGB and the nuclear industry. The main thrust of these is that energy consumption must increase to fuel our growth-orientated society and that this energy must be mainly nuclear-produced electricity. Views which challenge these assumptions are represented in the bibliography to their article, but the authors' discussion of the opposition views is limited. They thus dodge the central issue: if we can continue to expand our centralised high technology society whose built-in wastefulness demands such prodigious energy inputs, then who does this really benefit?

The nuclear debate is more about political than technical choices. G Kneale (1981 **16** 284–6) discusses the apparently technical question of health hazards and concludes 'Clearly at this stage we must leave the final decision to responsible politicians'. Unfortunately experience suggests that political responsibility is biased by external pressures. A prime example is the lead in petrol issue. Recently British politicians have been seen congratulating themselves for finally complying with EEC regulations and reducing the lead in petrol to 0.15 $g l^{-1}$ by 1985. This pathetic half-measure, in the face of well attested evidence of brain damage to children from airborne lead, avoids inconvenience to the UK motor and oil industries and has been bolstered by 'the demonstrably false yet largely unchallenged claims by ministers that most cars on the road would not run on lead-free petrol' (*The Guardian* 1 October 1981).

The history of the use of nuclear energy in the UK suggests that similar pressure from industrial lobbies operates. I hope that participants in the 'nuclear debate' will explore this. Perhaps, as the reference quoted on p282 suggests, 'nuclear power represents an unfortunate technological *cul-de-sac*', which may prove to be as irrelevant to real human needs as the pyramids and the vast concrete bunkers proposed for the MX missiles.

R W Howes
Camberley, Surrey

Surely G Kneale (*Phys. Educ.* 1981 **16** 284–6) misleads his readers in comparing radiation risks from nuclear power programmes to traffic accidents caused by speeding and drunken drivers. There may be numerical similarity if the risks are expressed in a particular way, but the choice for us, in electing the responsible politicians to whom Mr Kneale says we must leave the final decision, is based on a comparison of benefits and risks.

The benefits of speeding and drunken drivers are at most some pleasurable feelings in the speeder or drinker, and possibly his companions, offset by the probability of his own injury or death, or failing these, his guilty conscience in injuring or killing others. The benefits of nuclear power are on a much larger scale, relate to populations as a whole and, as Professor Fremlin so wisely points out (*Phys. Educ.* 1981 **16** 282–4), are probably more important for future generations than for our own.

E J Burge
Department of Physics, Chelsea College, London

SEXISM IN TEXTBOOKS

Geoffrey Walford's article 'Tracking down sexism in physics textbooks' (*Phys. Educ.* 1981 **16** 261–5) interested me. As director of the APPIL scheme, one of the texts analysed, my immediate reaction to his finding that girls get a poor deal (in terms of both illustrations and questions) was to plead guilty. In extenuation I would plead that, with so many novel features to concentrate on, the writing team should not be severely criticised for somewhat neglecting an aspect which, at that time, was less in public view. When a revision is made we shall clearly need to give attention to ensuring a better sex balance.

However, on reflecting a little upon the article, I think a few more points need to be made.

(1) It is very easy to add up female and male references in texts, and draw conclusions about bias, but this may well do a disservice to genuine equality of opportunity by concentrating on a superficial symptom, the alleviation of which would make virtually no difference.

(2) The most obvious conclusion to be derived from the data in the article is that *neither female nor males* figure significantly in physics books; in other words physics is presented as an *impersonal* study. While this is defensible in terms of the philosophy of the subject (the reproducibility of results by others, and so on), I would not myself wish to lay emphasis on this at school level. It may be the time is ripe for a 'personalisation' of physics, showing its relevance to people (girls, boys and adults).

(3) One must beware of the temptation to pretend things are as one would wish them to be. It is a fact that the vast majority of people engaged in physics and in physics-related activities are men, so to insist on *equal* numbers in illustrations could be said to be bending the truth. Only one degree worse is the female coalminer! I would not argue with *some*

disproportion (e.g. if 5% of physicists are female perhaps 20% or 25% shown in illustrations would be reasonable).

(4) Geoffrey Walford comes near to wanting to bend the truth in arguing against a historical framework for physics teaching because most significant discoveries have been made by men. Others (e.g. J W Warren 1981 *Phys. Educ.* **16** 210–1) have argued that concepts in physics cannot be properly appreciated *without* a historical perspective.

(5) The idea that a prosecution of a textbook writer under the Sex Discrimination Act would be helpful seems quite extraordinary. Whichever way the decision went it would almost certainly bring the concept of equality into disrepute, which is hardly Geoffrey Walford's intention.

(6) I would suggest that the sensible way forward is neither prosecution nor counting female heads, but ensuring that, when references to or illustrations of girls and women occur, they should carry the implication that females no less than males are able to do physics and physics-related activities (in contrast to the unspoken messages from pictures of women in kitchens or swimsuits). *John Bausor*

Inner London Education Authority, London

I was pleased to see the insistence on the problem of encouraging women physicists in the September issue of *Physics Education*. It is a subject of interest to me as a woman and a physicist, but there is a question I ask myself whenever I read speculations on the subject: are there perhaps some differences—whatever their root—in the ways that boys and girls like to think, and to look at the universe? I have read of some research, for example, that suggested that girls tend to have better developed nonverbal communication skills. If this were so, it would mean that girls would respond better to some forms of physics curriculum than to others. For example, I found that a class of girls responded well to the historically and philosophically based Project Physics course, despite a purported lack of interest in the subject.

I would be interested to know if any work has been done on whether girls respond better to, say, a Nuffield or SCISP approach than to a more traditional approach. It seems to me that this area might be much more important than that of sexism in textbooks. My suspicion is that we might find it to be the whole stance and style of a book that appeals more to boys, the illustrations in it being irrelevant.

I J Glaser

c/o Voluntary Service Overseas, London

While dusting my husband's books I came across the September 1981 issue of *Physics Education*. I was horrified to read in Geoffrey Walford's article on sexism in physics textbooks (*Phys. Educ.* 1981 **16** 261–5) what is in store for us girls. I was relieved to discover on page 302 of the same issue the sketches of masters and boys which shows that at least The Institute of Physics still strives manfully to maintain the old standards. *Elizabeth Clark*

East Grinstead, Sussex

STANDING WAVES

S R Hoon and B K Tanner, in their article on 'The physics of music' (*Phys. Educ.* 1981 **16** 300–11), discuss the standing wave patterns produced by closed and open pipes. They associate a compressional region with each node and a region of rarefaction with each antinode (see figures 5 and 6). This leads to two compressional regions per wavelength! In order to reduce the propagation of 'sound errors' I was prompted to write to point out to readers that alternate nodes are associated with a compressional region, the interlacing nodes being associated with a region of rarefaction. *C Isenberg*

Physics Laboratory, The University, Canterbury

S R Hoon and B K Tanner reply:

The confusion has arisen as we have not stated that the lower set of diagrams in figures 5 and 6 should correctly refer to amplitude rather than displacement. That nodal points are alternately compressional and rarefactional is readily seen by considering the sinusoidal displacement y that occurs at a point x in any longitudinal wave. For whilst the condition dy/dx = maxima defines all nodal points, its sign may be positive or negative corresponding to a rarefaction or compression respectively in the pressure wave. Further it should be noted that the pressure variation is phased shifted by $\pi/2$ with respect to displacement (see for example R T Weidner and R C Sells 1975 *Elementary Physics* New York: Allyn and Bacon p254 figure 16.2).

We wish to apologise for any confusion that our omission has caused and thank Dr Isenberg for bringing it to our attention.

PLANETARY MOTION

How many of us still tell our pupils that 'the earth goes round the sun'? The Einstein centenary articles (*Phys. Educ.* 1979 **14** 203–23) prompt the question whether we should amend our middle-school teaching to allow for the fact that Newton's system no longer holds sway. It is not the whole truth, even if

relativity is still the subject of various controversies. Newton's world view, which followed from Galileo's work and stand against the Inquisition, took absolute rest for granted although it was not disclosed by mechanics, so that the claim that the sun is at rest has always been too facile. I prefer to stick to the following.

(1) There is movement between any planet and the sun.

(2) The sun-centred model gives the simplest picture of planetary astronomy.

(3) Special relativity holds that there is no absolute standard of rest, but Einstein rejected it in favour of the new world view of general relativity, and philosophers are still arguing whether this, if true, involves absolute rest.

(4) If it does, the sun is not a strong candidate. In terms of stellar astronomy, it moves relative to the sky map of the distant stars, which are better candidates.

(5) Our ordinary experience that the earth is at rest should not be ignored; we should not be too ready to accept that it is hurtling through space even if this is a meaningful expression. *Frank R McManus*

Science Department, Fulham Gilliatt School, London

Queries in physics

Q510 (from *QIP*54)

Inside a space vehicle (well away from any disturbing stellar or other masses) there are two compartments, each hermetically sealed. One is filled with water but this has within it a centrally placed bubble of air. The other is filled with air but has a large, centrally placed drop of water. When the spaceship fires its accelerating rockets what happens to (a) the bubble and (b) the drop? And what will happen to them when the rockets stop firing?

Q511 (from *QIP*54)

Is there any readily explainable reason why the Appleton layer should refract radio waves? My ancient copy of Nelkon's *Light and Sound* suggests that this is virtually the same mechanism as occurs when light is refracted in a medium . . . but how then do we explain why x-rays can be totally reflected (at grazing incidence) from the surface of solid substances?

Q512 (from *QIP*54)

When my car radio is tuned to medium wave I often receive, very annoyingly, breakthrough of citizen band (CB) signals as their sources drive (and talk) past me. Causing interference to other equipment is of course illegal, but what is the mechanism by which a 27 MHz transmitter—AM in most present CB apparatus—causes a very strong signal at about 1 MHz? Curiously, if I switch to long wave whilst receiving medium wave interference, there is no breakthrough at all. Is no signal transmitted at 200 kHz or is it very weak compared with that on medium wave?

The above items were selected from *QIP*, a thrice-yearly broadsheet. It is available on subscription at a rate of £2 per annum (£2.30 overseas) from the editor, Mr W H Jarvis, Salewheel House, Ribchester, Preston PR3 3XU. All correspondence concerning this feature should be addressed to Mr Jarvis.

Films catalogue

Short reviews of over 500 films, videotapes and other audio–visual materials appear in *Audio–Visual Materials for Higher Education 1981–2*, which was published recently by the British Universities Film Council. The catalogue updates the 1979–80 edition, and covers most disciplines taught at university level, although many of the materials are also appropriate for sixth-form use. The BUFC has also produced a supplement listing film and videotape materials available for hire from the Higher Education Film and Video Library.

Audio–Visual Materials for Higher Education 1981–2 (price £8 UK, £9 overseas) and *HEFVL Catalogue Supplement 1981* (price 70p UK, £1 overseas) are available from Publications, BUFC, 81 Dean Street, London W1V 6AA.

Phys. Educ., Vol 17, 1982. Printed in Great Britain.

Teachers in training in physics—the current situation

J J Wellington

The number of students training to teach physics reached a 'low' of 244 in 1979–80 (Wellington 1981). The following year saw a remarkable upturn. The number of physics students in UDEs (university departments of education) rose from 182 to 288, while the number in other institutions rose from 62 to 143 (figure 1). This represents a total increase of just over 75%.

Where did this flood of recruits come from? Who are they? What degrees do they have? The only way to answer these questions was to write to each institution in turn, and this article summarises the more interesting results of a survey of the 27 universities and 30 polytechnics and colleges which were involved in 1980–81. All figures refer to replies received (over 92% of the sample—two universities and two polytechnics did not reply). In line with Graduate Teacher Training Registry (GTTR) procedure the two sectors are considered separately.

UDE students

Sex: According to replies received only 39 of the 288 students were women. At just over 13% this is even worse than the previous year's percentage of roughly 16% women (Wellington 1981). Where marital status was revealed it appeared that most of these women were single.

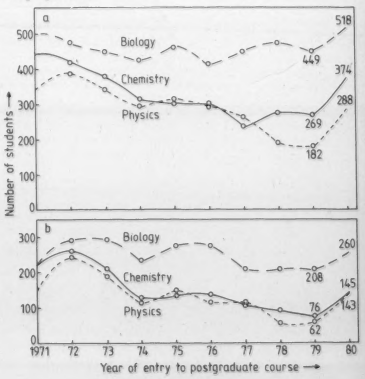
Age: The youngest students were 21 (not surprisingly), and the oldest physics student in a UDE was 59. Ages lay on a continuum between these two extremes, the most common age being 22. Just over half the students embarked on a postgraduate certificate of education (PGCE) course straight after their first degree.

Degree subjects: This question yielded the most interesting replies of all. The responses indicated that only 78 of the 288 trainee physics teachers had physics degrees. In other words less than 28% were physics graduates. This is an even lower percentage than in 1979–80 when roughly 38% of the trainees were physics graduates (Wellington 1981). Clearly then the sudden influx to PGCE physics courses in 1980 was in no way caused by an increased awareness, 'vocation' or interest in teaching amongst physics undergraduates. Of the remainder the majority were engineers of some sort: electrical, civil, mining, aeronautical, chemical . . . , and so on. Metallurgy degrees were quite common, as were general science degrees of various kinds. Joint degrees involving physics accounted for about 10% of the total. At least three chemistry graduates and five psychology graduates joined the physics groups for their PGCE.

Other first degree subjects are too varied and numerous to list fully (see table 1). They include fuel technology, mathematics, natural science, law, economics, ceramics, construction management, oceanography, nautical studies, biochemistry, statistics, marine biology, zoology and many others. Presumably all the graduates in these subjects studied physics to at least A-level.

Class of degree: Only *four* PGCE students in 1980–81 had first class degrees in physics. The classes of other degrees (where known) with at least some physics in

Figure 1 Students taking PGCE courses in **a**, UDEs; **b**, colleges and polytechnics



Jeremy James Wellington *is a lecturer in education at Sheffield University. On graduating from Bristol University he taught physics for seven years at Daneford School, Bethnal Green, then gained an MA in philosophy at London University. His main interests are the philosophy of science, the teaching of physics, and epistemology, and he has published articles in a variety of journals on these subjects.*

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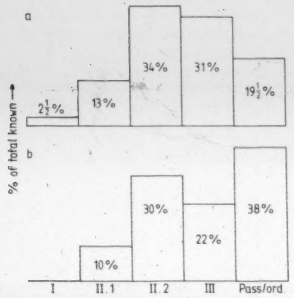


Figure 2 Classes of degree amongst 1980–1 physics PGCE students in **a**, UDEs; **b**, colleges and polytechnics

their 'label' are shown in figure 2a. Clearly the majority of trainee physics teachers (about 65%) have lower second class or third class degrees. Classes of degree in subjects without large elements of physics (e.g. economics, psychology) appear to be slightly higher though these have not been quantified. (Four students had Open University degrees.)

Some interesting cases: To my knowledge the oldest physics PGCE student in 1980–81 was born in April 1922—his first degree was in mining engineering (ordinary). At least five others were born in the 1920s, and later obtained degrees ranging from metallurgy to marine biology/oceanography. One married woman, born in 1949, obtained a first class physics degree from Oxford in 1970 (one of the four 'firsts' in England and Wales on PGCE courses).

Size of groups: The size of the physics groups varied from a minimum of 2 to a maximum of 21, with an average of just under 11. (The figures are obtained from the GTTR—the returns did not always tally with these, however.)

Other students

Sex: According to the replies (two institutions out of the total of 30 did not reply) only 12 of the 143 students studying physics as a main subject were women (just over 8%). Again the majority of these were single.

Age: Ages varied from 21 to 56. The average age was certainly *higher* than the average amongst physics students in UDEs. The replies indicate that more than half the students in this sector left a gap between their first degree and their PGCE course. In some cases the gap was as large as thirty years.

Degree subjects: The replies indicate that only 30 of the 143 students taking physics as a main subject had a first degree in physics, i.e. less than 21% had graduated in physics. The majority of the remainder had engineering degrees of some sort; some degrees were in metallurgy, several were joint degrees, e.g. mathematics/physics, physics/psychology and physics/chemistry. The others include archaeology, physiology, geology, biochemistry, pharmacy, liberal studies in science, business studies, environmental science, food science and many more. At least nine physics trainees had chemistry degrees. Their reasons for moving across to physics are not known from this survey.

Class of degree: Figure 2b shows the classes of degree, with at least some element of physics, amongst student teachers in polytechnics and colleges of higher education. There were no firsts in physics and only five with an upper second in a physics related degree. Three students with Open University degrees were noted. DES statistics show that, each year, just under 40% of physics graduates receive either a first or upper second class degree. This can be compared with the percentages in figure 2, although the comparison may be misleading since well under half of the students taking PGCE physics courses have degrees in physics.

Some interesting cases: The oldest PGCE physics student in this sector was born in 1924, and he obtained a lower second in physics in 1950. Another male, born in 1932, obtained an upper second in glass technology in 1956. One of the few married women on the course was born in 1942 and obtained a degree in pharmacy (pass) in 1964. Finally a 24-year-old male had an upper second class degree in archaeology.

Size of groups: The size of the physics groups varied from a minimum of 1 (studying physics as a first subject) to a maximum of 9. The average group size was just under 5. Numbers studying physics as a 'second' subject were not known from the survey—it is worth mentioning that (to my knowledge) many student teachers taking physics as a subsidiary or 'second' subject often apply for, and accept, jobs as physics teachers.

Questions raised by these findings

These attempts to delve into the sudden upsurge of recruitment to physics teaching raise several

Table 1 *Breakdown of degree subjects of PGCE physics students in UDEs*

Degree	*Approx. %*	*Degree*	*Approx. %*
Physics	28	Chemistry	1
Engineering degrees	11	Others: e.g.	1
Joint degrees (involving physics)	10	economics, biology, mathematics,	
General science degrees	7	philosophy, biochemistry,	
Applied physics	4	astronomy,	
Metallurgy	4	zoology,	
Psychology	2	oceanography	3

interesting questions. First, to what standard must a teacher be educated in a certain subject in order to go back to a lower level to teach that subject? Does a teacher need a physics degree in order to teach A-level physics? or a PhD in order to teach undergraduates? Professor Ziman, of Bristol University, makes some interesting comments on this question:

'. . . the science teacher should at least have passed successfully through the level of science *above* the level at which he is employed to teach. Thus the conventional qualification for teaching to degree level is a higher degree, such as the PhD, whilst school science to GCE A-level should be taught by science graduates, and cannot safely be entrusted to teachers whose professional training has not carried them significantly beyond the A-level standard, even though this might be quite adequate for the teaching of general science in the early years of the secondary school' (Ziman 1980).

Second, are graduates in physics likely to make the best physics teachers in *schools*? Would an engineering graduate, for example, be better placed in presenting a more lively, practical and 'applied' approach to physics teaching? Could the holder of a joint degree, in physics/chemistry for example, present a broader and more balanced approach to physics education than a highly specialised physics graduate? What about the graduates in subjects seemingly unrelated to physics mentioned above: archaeology, economics, biochemistry, business studies, and so on?

Third, are 'class of degree' and 'ability to teach' related (either directly or inversely)? The bulk of physics teachers at present training in UDEs have either a third or a lower second class degree, while those training in polytechnics and colleges of education have, as figure 2b shows, first degrees (on average) of slightly lower class. Do the best teachers have the best degrees? Are the qualities needed to become a 'good' teacher the same as those needed to acquire a good degree (Wellington 1981 p197)? Clearly this question is impossible to answer with any certainty. But it is worth considering, especially in the light of the recent DES scheme aimed at attracting 'firsts' and 'upper seconds' into physics teaching.

Finally, the percentage of women entering physics teaching is still lower than for any other subject on the school curriculum, except craft. How can the number of women on PGCE courses be increased? Clearly the problem goes right back to the third form in the secondary school, when choices are made. Physics is still seen as a 'boys' subject', and biology as the science for girls. Roughly four times as many boys take O-level physics as girls (DES 1981). This must certainly be a cause *and* an effect of the small percentage of women on PGCE courses in physics in the last decade.

Can more women be attracted into PGCE physics courses? The DES pamplet entitled *Teaching the Physical Sciences and Mathematics* (obtainable from Room 2/11, DES, Elizabeth House, London SE1 7PH) must repel more women than it attracts. The four photographs it contains show male teachers in situations which 'smack' of the 1950s. Surely a more attractive image of mathematics and science teaching could be presented than the one portrayed in this pamphlet.

References

DES 1981 *Statistics of Education Vol. II 1970–8* (London: HMSO)

Wellington J J 1981 'Training physics teachers' *J. Educ. Teach.* 7 May

Ziman J 1980 *Teaching and Learning about Science and Society* (London: Cambridge University Press) p14

HAVE YOU READ THIS?

Abstracts submitted by T B Akrill, E Deeson, R W Fairbrother, W H Jarvis, P E Richmond and J Solomon.

Interdisciplinarity

Does the integration of science necessarily imply the creation of a rag-bag subject called integrated science? These two Italian scientists, one a physicist and the other a biochemist, reflect on the place of interdisciplinarity both in primary school, for interacting with children's out-of-school knowledge, and much later, for the exploration of real social problems—but without neglecting the role of scholastic science. *JS*

M Arcà and M Vicentini-Missoni *European Journal of Science Education* 1981 **3** 117–26

Alternatives for science education

There has been distressingly little public discussion of this 1979 ASE consultative document, which as background to the recently published ASE policy statement *Education through Science* may well prove to be of greater long-term significance than many of us expect (hope?). These two articles breathe life into the debate and in so doing focus

attention at the school–university interface, an area of particular concern to readers of this magazine. *TBA*

D H Jennings *Journal of Biological Education* 1981 **14** 223–30; R W West *Journal of Biological Education* 1981 **15** 42–6

Science in the common curriculum

Have you been able to follow the appalling complexities of the debates about 'cores' and examinations? Here, price 25p from *Education*, is a pull-out which will remind you of all the background from the Great Debate to the recent DES and Schools Council papers. Even the varieties of possible cores and options are described. *JS*

An Education Digest ED. S. ED M/8 1981

Glass

This article covers how glass is made, what it is and different kinds of glass and their properties. There are some useful tables of data and graphs of behaviour. It is applicable at all levels from middle secondary school upwards. *RWF*

M G Britton 'Glass as an engineering material part 1' *Physics in Technology* 1981 **12** 187–95

Energy storage

There are two main types of thermal store: 'sensible heat' stores involving a change of temperature, and 'latent heat' stores involving a change of phase. This is a very useful article summarising different ways of using these two main types. There are some good diagrams, useful data and references for further reading. *RWF*

W E J Neal 'Thermal energy storage' *Physics in Technology* 1981 **12** 213–20, 226

Evidence for atoms and molecules

Three sorts of 'evidence' (not 'proof') are quoted: (i) reasonably cogent evidence, (ii) less conclusive evidence and (iii) items having little or no bearing on the issue. The article is short and could be read with interest by sixth formers. *TBA*

P G Wright *Education in Chemistry* 1981 **18** 74–5

A small heat wheel for the classroom

A heat wheel is a segmented wheel packed with material which will readily absorb and release heat energy. It is installed in ventilation systems so as to extract the heat in exhaust air and put it back into incoming air. This article shows how to make a model, and how to show that it works. *WHJ*

G C Hudson *School Science Review* 1981 **63** 94

Mixed ability teaching

This article is the outcome of attempting to evaluate the relative effectiveness of teaching mixed-ability groups and groups setted by ability. The method had the advantage of using the same sample of children in both situations. *WHJ*

J A Plewes *School Science Review* 1981 **63** 163

Interfacing microprocessors

This article gives practical help in the form of a range of practical circuits, for those who wish to interface microprocessors to electronic and electromechanical systems. *WHJ*

J D Ferguson, J Stewart and P Williams *Wireless World* October 1981 **87** 34

Educational satellite

Although very few schools have been using the many satellites put up primarily for educational purposes, sufficient enthusiasm has arisen in the UK for our own satellite to have been due for launch (in a flurry of media apathy) early in October. In particular the v.h.f. and u.h.f. beacons should provide a reliable link to ground for reception by amateur stations. *WHJ*

Wireless World October 1981 **87** 40

Charge leakage

There is no reason why negative and positive charge leakage from an insulated conductor should be equal; this experiment confirms that they are not. *WHJ*

J C Siddons *School Science Review* 1981 **62** 746

Microcomputers in science teaching

Are teachers all over the country doing their best but actually all writing poor programs on the same topic? *WHJ*

N Rowbotham *School Science Review* 1981 **63** 70

Solar Ponds

Salt water overlaid by fresh water becomes heated by the sun and the density gradient prevents mixing by convection. In Israel a 150 kW electric generator has been built operating between the top (cold) and bottom (hot) layers of a pond. This is a definitive account by the expert, and includes 45 references. *PER*

H Tabor *Solar Energy* 1981 **27** 181–94

Solar thermal power

This is a special issue covering all aspects of the use of parabolic troughs and dishes in solar heat and power systems. *PER*

Sunworld 1981 **5** no 3

The great high-speed train race

The approaches to 200 $km\,h^{-1}$+ rail transport in Britain, France, Canada and Japan are very different. The designers are meeting different problems, but the major difficulty is always the track. Braking and tilting are also examined closely in this detailed survey of current technologies. *ED*

J Stansell *New Scientist* 1981 **91** 710–3

The ionosphere from the pole

New developments in ionosphere studies in the Antarctic should make the most of the special conditions near the Pole—high dip, aurorae, seasonal rather than diurnal variation, asymmetries. Current work, problems and hopes are described in the context of ionospheric studies. *ED*

J Dudeney *New Scientist* 1981 **91** 714–7

Fusion feels the pinch

The control of the plasma in a fusion reactor remains the main obstacle in the way of successful fusion power. The reversed field pinch shows great promise but is threatened by Government cuts. This piece puts the technique in context and argues for more research on it, rather than less. *ED*

M Kenward *New Scientist* 1981 **91** 788–9

The future in space

A special set of articles on current plans and possibilities: the Shuttle, plans for a Soviet space station, solar power stations in orbit, exploiting the moon, robot exploration of the solar system, military satellites. *ED*

New Scientist 1981 **92** 12–40

The birth of the planets

The origins of the solar system remain unknown. Currently proposed models are described and compared. *ED*

N Henbest *New Scientist* **92** 173–6

Phys. Educ., Vol 17, 1982. Printed in Great Britain

Physics on stamps: Appendix XII

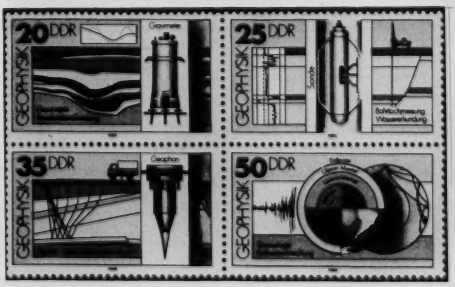
E J Burge
Chelsea College, London

A list of stamps relating to physics issued between the 1981 and 1982 Gibbons Stamps of the World *catalogue.*

The article and appendix I under this title are to be found in *Physics Education* 1971 **6** 357–61. Successive annual appendixes have been published in *Physics Education*. The 23-page booklet listing all the stamps relating to physics previous to the appendixes, together with copies of the first 11 appendixes, are available from the author, price £2.65, including postage.

The issues depicting the Arabian Avicenna (or Ibn Sina) relate to the 1000th anniversary of his birth in 980. He was famous as physician, scientist, mathematician and philosopher. Al-Biruni (or Al-Beruni) was an Arabian mathematician, astronomer and historian, 973–1048.

A recent book *Physics on Stamps* by R L Weber (1980 London: Tantivy) provides entertaining comments on many physicists represented on stamps, together with chapters on equations, organisations for international cooperation, an international system of measurement, space exploration, concern for energy, inventions and technology for better living, and Nobel prizes. It makes no attempt to



Sketches of Kepler and Copernicus appear on the stamp from Mali commemorating the 350th anniversary of Kepler's death (**left**); gravimetry, bore-hole measuring and seismology are the topics of stamps from East Germany on the theme of geophysics (**bottom left**); and the 1000th anniversary of Ibn Sina's birth is commemorated on a stamp from Tunisia (**below**)

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provide complete lists or philatelic information. The numerous black and white illustrations are unfortunately poor in quality, and the coloured plates mentioned in the index and on the jacket are not in the book itself.

Note that Gibbons' *Stamp Monthly* provides information each month on new issues. The 1982 *Stamps of the World* catalogue contains all stamps listed in this *Stamp Monthly* up to and including June 1981.

General physics stamps. MS *indicates miniature sheet*

Country	*SG no.*	*Description*	*No.*	*Catalogue value (mint)*
Benin	764,5	(50th anniversary of discovery of Pluto) Kepler, Copernicus	2	90p
Canada	988	(Uranium resources) Uraninite molecular structure	1	70p
Congo Republic	723	(Commemoration) Claude Chappe and semaphore tower	1	£1.10p
Cook Islands	703–11, MS 707	(350th death anniversary of Kepler, 75th death anniversary of Jules Verne) Kepler, Verne	8 + MS	£1.94p + £1.25p
Cook Islands (Aitutaki)	284–9 MS 290	(25th death anniversary of Einstein) Einstein, $E = mc^2$, nuclear explosion	6 + MS	74p + £1.00p
Cuba	2628	(Intercosmos programme) Physics of the cosmos	1 of 6	5p
East Germany	E2215	(Celebrities birth anniversaries) F Joliot-Curie (80th)	1 of 6	5p
East Germany	E2253–6	(Carl Zeiss Optical Museum) Microscopes by Huntley, 1740; Magny, 1751; Amici, 1845; Zeiss, 1873	4	£2.05p
East Germany	E2273–6	(Geophysics) Gravimetry, bore-hole measuring, seismology	4	£2.05p
France	2372	(Earth sciences) Symbol of sources of energy	1	55p
Greece	1512,3	(2300th birth anniversary) Aristarchus theorem, heliocentric system	2	70p
Hungary	3348	(350th death anniversary) Kepler	1	15p
Iceland	593	(50th anniversary state broadcasting) Early microphone	1	£3.00p
India	959	(Institution of Engineers) Symbols of energy	1	5p
Iran	2150	(1400th anniversary of Hegira) Al-Biruni, Farabi and Avicenna	1 of 4	10p
Iran	2135	(550th death anniversary) G J Kashani and astrolabe	1	15p
Ireland	474	(Irish science and technology) Boyle and air-pump	1 of 4	25p
Italy	1635	(Europa) Antonino Lo Surdo, geophysicist	1 of 2	20p
Japan	1582	(8th world computer conference and 3rd world conference on medical informatics) Integrated circuit	1	30p
Kuwait	880,1	(Birth millenary) Iba Sina	2	45p
Libya	1019,20	(Birth millenary, school scientific exhibition) Avicenna, emblem	2	50p
Mali	755–8	(Solar energy) Various solar generators	4	95p
Mali	766,7	(350th death anniversary of Kepler) Kepler, Copernicus, diagrams	2	£1.05p
Mali	768	(50th anniversary of discovery of Pluto) Pluto and orbit diagram	1	90p
Mali	772,3	(Birth millenary) Avicenna	2	60p
Mexico	1514	(Centenary of electric light) Edison lamp	1	8p
Mongolia	MS 1315	(350th death anniversary) Kepler	MS	(–)
North Vietnam	262,3	(Birth centenary) Einstein, equation, sun and planets	2	30p
Russia	5022	(Birth millenary) Ibn Sina	1	10p
Russia	5043	(Birth centenary) A F Joffe	1	10p
St Lucia	MS 562	(Nobel prize winners) Einstein	MS of 4 + MS	£1.90p
Sweden	1059	(Nobel prizewinners, 1920) Walther Nernst	1 of 4	70p
Tunisia	950	(Birth millenary) Ibn Sina	1	40p
Tunisia	951	(The Arabs) Arab and geometric diagram	1	20p
Turkey	2718,9	(Birth millenary) Ibn Sina	2	85p
USA	1787	(Black Heritage) Banneker, astronomer and mathematician	1	15p
West Germany	1928	(Europa) Leibnitz	1 of 2	25p

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Lissajous' figures revisited

B A Smith and E M Smith

A previous article (Smith 1981) described the application of a digital technique in order to generate the simpler Lissajous' figures, making use only of the line printer provided at a terminal. The aim is twofold: to learn something about the patterns themselves but also to use this problem to give point and purpose to the acquisition of computing skills. The purpose of this article is to extend these ideas to more complex patterns, providing new insight into a particular class of such figures for which the frequencies are in the ratio 3 : 2. Here the need to handle increased amounts of data leads to the development of a more sophisticated computer program which, by making use of the one DIMensional array facility, has considerable elegance and a wider range of application.

Digital method

The formation of Lissajous' figures is achieved by means of the orthogonal combination of two simple harmonic motions so as to produce a closed figure in the xy plane. These motions are represented by

$$\begin{aligned} x &= X_0 \cos \omega t \\ y &= Y_0 \cos(N\omega t + \varepsilon) \\ \varepsilon &= M\pi/4 \end{aligned} \tag{1}$$

where the symbols have their usual meaning.

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For the point-by-point generation of Lissajous' figures using computational methods it is convenient to consider the rotating vector model shown in figure 1. The x direction is taken to correspond to the direction of paper travel in the printer (or to the direction of line 'printing' on the VDU), so that for the simpler stationary patterns for which N is integral there are only two roots, y_1 and y_2, for each value of x. In general these roots are separate and distinct for values of ε other than 0 or π, for which the roots are coincident.

More generally the ratio of the possible roots (x_{n2}, y_{n1}) corresponds to that value for the frequency ratio, $N = N_2/N_1$. Thus for N fractional and restricting N_1 and N_2 to small integers, the computer program needs to be modified so as to generate the requisite number of roots y_j at each value of x in the interval 0 to $2X_0$. Referring to figure 1, as the X_0 vector rotates the angle A goes from 0 to π and then from π to 2π sequentially, effectively retracing its path since $\cos A = \cos(2n\pi \mp A)$. This is indicated by the arrows marked on the solid curve which represents the variation in the magnitude of x. Thus the two leading members of the series of angles A_j are

$$\begin{aligned} A_1 &= \arccos(1 - x/X_0) \\ A_2 &= 2\pi - A_1 \end{aligned} \tag{2}$$

from which the corresponding series of angles $B(J)$ is derived in the form of a one DIMensional array. Since relatively few members of the series are needed (J = 8 as an arbitrary choice) it is simpler to form each term separately, rather than to establish a new loop.

The advantage of making use of the DIM facility is that it simplifies the handling of the increased amount of data by means of 'shuffle' subroutine. At each value of x this subroutine will arrange the values $Y(J)$ in increasing order of magnitude, eliminate the duplication of equal roots and so present the ordered data to the teletype (or VDU) for printing. Examples of these patterns, generated by line printer, are shown in figure 2 for those cases for which N = 1.5 and $\varepsilon = 0, \pi/4$ and $\pi/2$.

Now it may be shown that the generalised, time-independent equation, for N = 1.5 and any ε, may be derived from equations (1) to give

$$\begin{aligned} 4y^2 - 2 = (x^3 - 3x)\cos 2\varepsilon - (x^2 - 1) \times \\ (4 - x^2)^{1/2} \sin 2\varepsilon \end{aligned} \tag{3}$$

where for convenience the amplitude X_0 = 2 and Y_0 = 1 unit. This family of curves all fit within the rectangle, of sides 4 and 2 units respectively, centred on the origin and with the x direction the principal axis symmetry. Then for particular cases:

$\varepsilon = n\pi$

$$4y^2 = x^3 - 3x + 2 = (x + 2)(x - 1)^2 \tag{3a}$$

$\varepsilon = (2n + 1)\pi/4$

$$(4y^2 - 2)^2 = (x - 1)^2 (2 - x)(2 + x) \tag{3b}$$

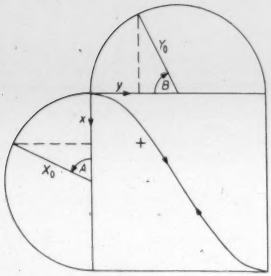

Figure 1 Rotating vector diagram

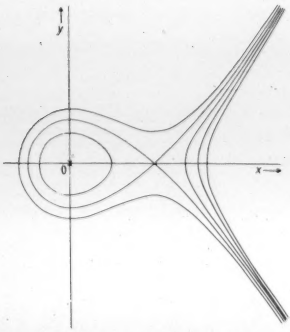

Figure 3 Family of curves represented by $4y^2 = (x^3 - 3x^2 + c)$ where $c = -2, 0, 2, 4$ and 6; the relation between them is of successive contour lines of a surface, as in the neighbourhood of a pinnacle on a mountainside (*after Lamb 1949*)

$$\varepsilon = (2n + 1)\pi/2$$
$$4y^2 = 2 + 3x - x^3 = (2 - x)(x + 1)^2 \quad (3c)$$

These equations correspond to those patterns shown in figure 2; thus equations (3a) and (3c) have three roots in x, two of which are identical, and represent those 'α curves' shown in figures 2a and c to have opposite orientation (x replaced by $-x$).

Following Lamb (1949) this type of curve is seen to belong to a set of curves given by the equation

$$ay^2 = (x - \alpha)(x - \beta)(x - \gamma) \quad (4)$$

where $\alpha < \beta < \gamma$ and shown plotted in figure 3. This set of curves resembles the successive contours in the vicinity of a pinnacle on the side of a mountain. In particular, the nodal curve is identical with the Lissajous' figure (discussed above) and occurs when the two greater quantities, β and γ, coincide so that

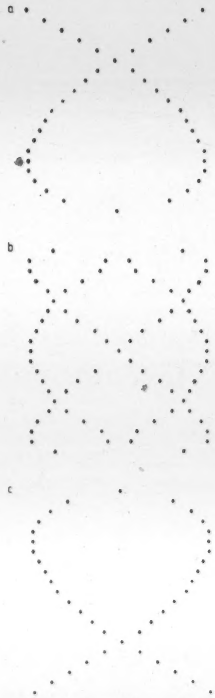

Figure 2 Line printer output for $N = 1.5$ and **a**, $\varepsilon = 0$, **b**, $\varepsilon = \pi/4$ and **c**, $\varepsilon = \pi/2$

$$ay^2 = (x - \alpha)(x - \beta)^2$$

These curves, as plotted by Lamb, have the specific formula

$$4y^2 = x^3 - 3x^2 + c$$

where, in the case of the nodal curve, $c = 4$; so that

$$4y^2 = (x + 1)(x - 2)^2 \quad (5)$$

Equations (5) and (3a) are then identical in form but with different origins; shifting equation (5) to a new origin at (1,0) gives equation (3a).

Conclusion

The point-by-point digital plotting technique has been extended to a higher level of complexity showing

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A simple microprocessor breadboard system for use in microelectronics or computer education—part 1

M K Summers

Microelectronics is currently receiving massive attention in the curricula of educational institutions from lower secondary school right through to postgraduate university level. In the United Kingdom, for example, there is now an electronics O-level course which places considerable emphasis on microelectronics (Associated Examining Board 1980), while science and engineering departments in universities, polytechnics and colleges throughout the country are increasingly developing courses concerned with microelectronic devices and their applications. In 1979 £9m was allocated to a microelectronics development programme for schools and colleges (Department of Education and Science 1979) and 30 or so projects are currently being financed (Coll 1980).

Microelectronics is however a broad term, and integrated circuits for example have been around since the early 1960s. In fact microelectronic devices of this kind have long been dealt with in the curricula of tertiary institutions, and have also been widely studied and used in secondary schools. The real microelectronics *revolution* dates from the early part of the 1970s with the development of the *microprocessor*—the central processing unit of a digital computer fabricated on a single integrated circuit chip. It is the microprocessor and the associated products of the large scale integration of electronic circuits (RAMs, ROMs and so forth) which will have the biggest impact on our lives and which will be studied increasingly in schools, colleges, polytechnics and universities.

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These two articles are concerned with learning about microprocessors through experiment, and to this end describe the construction of a simple system which can be used in courses at any level concerned with microprocessor hardware, software or applications. A variety of microprocessor development systems are, of course, available commercially at low cost (see for example Summers 1978) but these are constructed on printed circuit boards with a resident monitor program in ROM, and as such are rather inflexible. The system described in these articles has the following advantages when compared with commercial systems:

(1) It is constructed mainly on *breadboard*, so that very little soldering is required. Integrated circuits and interconnecting wires are simply pushed into the appropriate holes in the breadboard matrix.

(2) Because of this, the system is very *flexible*, i.e. it is easy to change connections, add extra chips, make connections to external devices for control purposes, and so on. This makes it ideal for use in educational settings where hardware functioning and the design of microprocessor systems are under study.

(3) The monitor program is loaded into RAM, and can be designed by the user to suit his or her own requirements (a sample monitor program is given). Although a tedious process, this has two important advantages. First of all, schools in particular may not have facilities for developing and 'burning in' ROMs, and so construction of a system requiring RAM only is a realistic project for them to tackle. Secondly, students are able to design, load and evaluate their own monitor programs (which can be of various levels of complexity). Apart from being a useful exercise in machine language programming, this is a good introduction to the concept of an operating system. It should perhaps be mentioned that although loading a monitor into RAM can be tedious (depending on its length), the CMOS chips used have a low power memory retention facility so that programs can be retained as required with only a very small current drain from a back-up battery supply. Of course, if control of external devices is all that is required, no monitor program is necessary. By loading the starting address at the appropriate RAM

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location (later), the microprocessor can execute any program to control the device.

The cost of construction is not particularly low, the most expensive item being the breadboard itself (around £20 at current prices). An estimate of cost excluding breadboard is currently about £50, but anyone building, testing and using this system will learn a lot about microprocessors, and will end up with a useful piece of teaching equipment.

Design

It must be made clear at the outset that the purpose of this article is *not* to provide an introduction to microprocessors *per se*, although descriptions throughout will be sufficiently detailed to allow someone with only a rather elementary knowledge of these devices to follow what is going on. The system to be described uses the popular Motorola MC6802 microprocessor, and some familiarity with this chip or the associated and more widely used MC6800 is assumed. Readers without this knowledge can find accounts in many texts, but the author would particularly recommend the excellent book by Bishop (1979) since it assumes no prior knowledge and strikes a nice balance between descriptions of hardware and software. Bishop's book describes the MC6800, but as far as software is concerned the two chips are identical.

The advantage of the MC6802 is that it contains an on-chip clock and 128 bytes of on-chip user RAM. In fact it is this RAM which is designated in the present design for the development and storage of user programs. Although this is only a very small amount of memory, it is quite adequate for writing the kind of simple machine language programs that one might include in basic courses dealing with microprocessor software and elementary applications. Additional RAM can, of course, be added externally if required. It is perhaps worth noting that a simple microprocessor system based on the MC6802 has been described elsewhere (Huffman 1979) but this is a more traditional design with a monitor program in ROM and is unfortunately lacking in clarity of exposition. It may however be a useful background reference for anyone tackling the present project.

A labelled photograph of the complete system is shown in figure 1, while a complete circuit diagram is given in figure 2. The major design features to be noted are as follows.

(1) Eleven integrated circuits (i.c.s) are used, all of which are plugged directly into the breadboard.

(2) The prototype shown in figure 1 used two QT-59S breadboard sockets and three QT-59B bus strips manufactured by Continental Specialities Corporation, but a variety of similar boards are available from other manufacturers. The QT-59S sockets are 59 holes long with groups of five

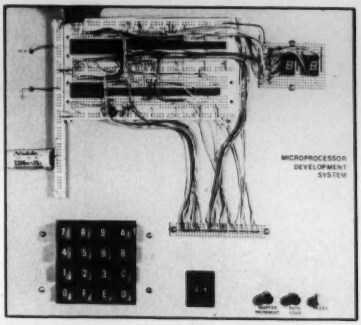

Figure 1 The completed system. Note the pair of thumbwheel switches (bottom centre between the keyboard and the address increment switch) and the crystal (top left). Integrated circuits from left to right are (top) MC6802 microprocessor, 2 × MCM145101 RAMs, 2 × MC14495 latch/decoder/drivers and (bottom) MC14515B decoder, MM74C922 keyboard encoder, 2 × 74LS367A hex buffers, MC14520B dual binary counter and MC14011B quad NAND gate

connected holes arranged vertically either side of a central dividing groove. The physical arrangement of the i.c.s on these boards is indicated in figure 1, but note that a different layout may be necessary if boards from other manufacturers are used (available dimensions vary). In the layout of figure 1 there is space for a third board beneath the upper two. This will be required if additional memory or i.c.s interfacing to the outside world (A–D converters, PIAs, buffers and so on) are required.

(3) All addresses and data are monitored by a pair of seven-segment LEDs (details are given later when the design of a suitable monitor program is considered). It is convenient to mount these on a small piece of stripboard as shown in figure 1, although they can be plugged into additional breadboard if this is available. The LEDs are driven by a pair of CMOS MC14495 BCD-to-7 segment hexadecimal latch/decoder/driver i.c.s tied directly to the data bus. The right-hand LED monitors data lines D_0–D_3 (least significant hex digit) and the left-hand LED data lines D_4–D_7 (most significant hex digit).

(4) Two 256 × 4-bit CMOS MCM145101 RAMs are used to store the monitor program. By wiring their address lines in parallel and using the data lines separately it is possible to store and access 256 × 8-bit binary words (i.e. the monitor program can be up to 256 bytes long). The advantage of these particular RAMs is that they have *separate* input and output data lines (an unusual facility). In the present design the monitor program is loaded by setting the appropriate binary words on a pair of hexadecimal-

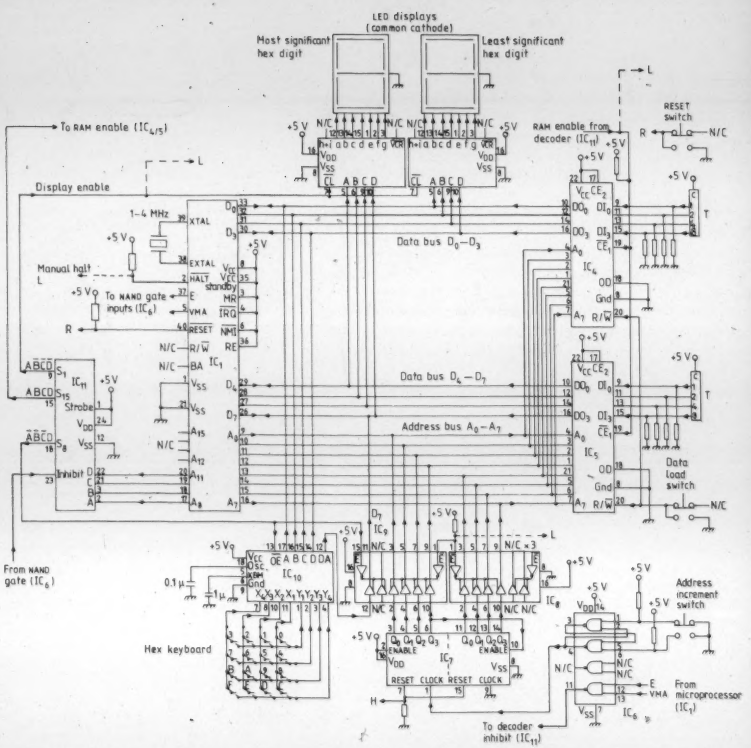

Figure 2 Full circuit diagram. RS Components supplies most of the parts including hex thumbwheel switches and keyboards, crystals, 145101 RAMs and 74C922 encoders. All components are widely available (see advertisements in electronics magazines). IC_1, MC6802 microprocessor; IC_2 and IC_3, MC14495 BCD-to-7 segment hexadecimal latch/decoder/driver; IC_4 and IC_5, MCM145101 256 × 4-bit static RAM; IC_6, MC14011B quad 2-input NAND gate; IC_7, MC14520B dual binary up counter; IC_8 and IC_9, 74 LS367A hex 3-state buffer with separate 2- and 4-bit sections; IC_{10}, MM74C922 16 key encoder; IC_{11}, MC14515B 4-bit latch/4-to-16 line decoder (only 3 of 16 outputs are shown—the rest are not connected). All resistors are 100 kΩ and monitor load connections as shown dotted. T, thumbwheel switch (output encoded in hexadecimal). Connect points L low during monitor load. Connect point H high to reset counter before monitor load. R, To reset pin (microprocessor)

output-coded thumbwheel switches, the outputs of which are fed directly to the four data input lines of each RAM. The RAM enable inputs $\overline{CE1}$ are physically wired low during a monitor load operation so that depressing the data load switch forces the RAM R/$\overline{W}$ line momentarily low and the word is stored in the addressed memory location. The eight paralleled address lines of the RAMs are driven via a pair of 74LS367A hex tristate non-inverting buffers by an 8-bit binary counter (in fact the two halves of an MC14520B dual 4-bit binary up counter wired together to make an 8-bit counter).

Before a monitor load sequence the hex buffers are first enabled by wiring their $\overline{E}$ lines low. The counter is then zeroed by momentarily wiring its reset pins high, and the first monitor byte loaded into the lowest memory location (00) by depressing the data load switch. The counter is then incremented by depressing the address increment switch (which drives the counter clock input via the dual NAND gate debouncing circuitry wired around IC_6), the thumbwheel switches set to the next monitor byte,

data load depressed, and so on until the entire monitor program has been loaded. During this process the microprocessor should be in the HALT state ($\overline{\text{HALT}}$ line wired low) so that it is isolated from the address bus, and the displays enabled by wiring the driver/decoder $\overline{\text{CL}}$ lines low. The latter connection allows each monitor byte to be displayed in the LEDs as it is loaded.

On completion of the monitor load sequence the four temporary connections (shown dotted in figure 2) are restored to their original form. This means that the hex buffers are tristate and isolated from the address bus, the microprocessor is no longer halted, and the display and RAM enables are driven by the 4-to-16 line decoder and are hence under microprocessor control (later). Note that apart from during the monitor load sequence the RAM $R/\overline{W}$ lines are permanently high (read only state). In effect this means that, as far as the microprocessor is concerned, the RAMs are acting as a monitor ROM. The separate input and output data lines of the RAMs allow this RAM/ROM function to be implemented very easily.

(5) When the microprocessor is released from its HALT mode or when the RESET switch is depressed, the monitor program will be executed, i.e. the monitor program will be in control of the system. Typically this program will scan the keyboard for key depression and release, display entries in the LED displays, store user program bytes in the 128 bytes of RAM on the MC6802 microprocessor chip (the user RAM), and provide facilities for executing programs, storing results and debugging programs. The range of facilities available will depend on the complexity of the monitor program (a simple one will be described later).

(6) The 128 bytes of user RAM on the MC6802 occupy hex addresses 00 to 7F and are connected internally to the address bus. External devices are addressed by decoding microprocessor address lines A_8–A_{11} using the MC14515B 4-to-16 line decoder chip. Each one of the 16 possible combinations of binary digits on these four address lines causes one of the 16 decoder outputs S0 to S15 to go from its normally high to a low state. These low going signals can be used to enable up to 16 external devices at 16 distinct addresses. In the configuration of figure 2 only three external devices are accessed, i.e. the display, the hex keyboard and the external RAM. These are enabled by decoder outputs S1, S8 and S15 respectively (an arbitrary choice). Since microprocessor address lines A_{12}–A_{15} are not connected, the display responds to address X1XX, the keyboard to X8XX and the external RAM to XFXX (where X represents *any* hex digit). In practice we shall write the irrelevant digits as zeros, so that these addresses become 0100, 0800 and 0F00 respectively. Note that under this decoding scheme the monitor program is stored in addresses 0F00 through to 0FFF, and that up to 13 more external devices can be accessed using the 13 unused decoder output lines. Decoding of unused address lines A_{12}–A_{15} would, of course, allow further expansion.

(7) The hex keyboard through which user programs are entered, debugged and executed is fully encoded and debounced by the MM74C922 encoder chip IC_{10}. It should be noted that a variety of hex keyboards are available and the physical arrangement of keys may differ from that shown in figure 2 (in fact the keyboard used in the prototype system of figure 1 has a different key layout). This does not matter provided care is taken to wire each key to its correct row/column input of the encoder chip. For example, key 9 *must* be wired to X_2/Y_3 whatever its position on the keyboard, and so on. The encoder itself has tristate outputs allowing direct connection of its four encoded data output lines to the lower four microprocessor data lines D_0–D_3. When a key is pressed a data available pulse (DA) is fed from IC_{10} to microprocessor data line D_7 via a non-inverting tristate buffer. The monitor program can therefore detect a key closure and release by testing D_7. This technique is illustrated in the sample monitor program described later.

(8) Finally, note that the system clock (internal to the MC6802) is controlled by a crystal of resonant frequency between 1 and 4 MHz. In fact the MC6802 divides this frequency by 4, so that with a 4 MHz crystal the system runs at its maximum frequency of 1 MHz. The clock signal E is output from pin 37 of the microprocessor, and in the present design this is NANDed with the VMA output from pin 5 and used to synchronise decoder IC_{11} via its inhibit input.

Construction and testing

Apart from the two low-power Schottky hex buffers, all i.c.s are CMOS and must be handled with caution to prevent exposure to excessive electrostatic voltages. In practical terms this means keeping the chips in the conducting carriers in which they are supplied by the manufacturers until they are actually plugged in to the breadboard, and not wearing clothing such as nylon shirts or working on surfaces which are easily charged electrostatically. To be completely safe it is best to work on an earthed metal surface and ground the body with an earthed length of bare wire wound around the wrist, but these rather excessive precautions are not really essential with modern CMOS devices which incorporate protective circuitry to guard inputs against damage due to high electrostatic voltages (they were certainly not taken when the present system was constructed). Note that the inputs of CMOS devices must not be allowed to 'float' and must therefore be tied to either the positive

or negative supply rails, through 'pull-up' or 'pull-down' resistors if necessary. This aspect of design is apparent from figure 2 (which, of course, includes resistors where necessary).

Construction itself is simply a matter of plugging in the i.c.s and wiring all pins according to the circuit diagram. In the design implementation of figure 1 all wires from the keyboard, the two thumbwheel switches and the top panel press-button switches are connected to the underside of double-sided terminal pins mounted along a narrow piece of matrix board. Wires soldered to the top side of these pins (visible in the photograph) are then taken to the appropriate breadboard holes. A suitable 5 V smoothed power supply is, of course, required and can be connected to the side of the unit via two 4 mm sockets. Two wires from these sockets are led to the surface and pushed into the bus strips as shown in the photograph.

In practice the best approach to construction is to assemble and test the system in stages. The first step should be to connect the keyboard, thumbwheel switches and push-button switches to the underside of the matrix board terminal pins, and then plug in and wire up the keyboard encoder i.c. Correct encoding action can be checked by monitoring the i.c. data outputs with a multimeter (or an oscilloscope used as a d.c. voltmeter). Following this the LED displays should be wired up and connected to the two latch/decoder/driver i.c.s. The keyboard encoder outputs can be connected temporarily to the latch/decoder/driver data inputs to check that the displays function correctly. A sensible next step is to plug in and wire up the quad NAND gate debounce section, the binary counter and the two hex buffer i.c.s, and check the enabled buffer outputs for correct counting from 0 to 255 for consecutive depressions of the address increment switch. The two RAMs can then be plugged in and connected up, and their enabled outputs connected to the display latch/decoder/drivers while data from the thumbwheel switches are loaded at their inputs. This RAM test can be followed by a test of the 4-to-16 line decoder i.c. (although this can in fact be done at any stage). The decoder outputs are simply monitored while the logic levels at its A–D inputs are altered. Finally, the microprocessor is added and the wiring completed. After the crystal has been plugged into pins 38 and 39 the clock output (E) at pin 37 can be checked using an oscilloscope. But further testing really requires that a suitable test program be loaded into the external RAMs via the thumbwheel switches. This procedure will be described in part 2 of this article, to be published in the March issue.

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continued from p13

the increasing usefulness of computational methods in handling increased amounts of data and, at the same time, showing that there are still novel aspects of well established topics waiting to be discovered.

It is important to note that BASIC exists in many fine gradations of sophistication and such an idiosyncratic language needs to be interpreted. Thus for the program described here there is no stored π and this symbol is not recognised. Other, minor variations are differences in the use of the various punctuation symbols. Similarly, DIM *Y* (*J*) is not accepted if *J* is a variable; however for $J \leqslant 10$ most BASIC systems do not require the lengths of such arrays to be specified explicitly.

The listing of the program described here can be obtained by sending an SAE to Dr B Smith, Department of Physics, University of Sheffield, Sheffield S3 7RH. The listing for a modified program, adapted to run on the ZX81, can also be obtained from Dr Smith.

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Phys. Educ., Vol 17, 1982 Printed in Great Britain

The use of satellites by schools and colleges—part 2

D A Duff

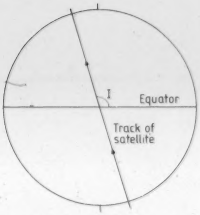


Figure 1 The track of a satellite makes an angle I—the satellite's inclination—to the equator

Part 1 of this article (*Phys. Educ.* 1981 **16** 352–6) described the AMSAT Oscar satellites, the NOAA weather satellites and the information they transmit. Part 2 deals with how to locate a satellite and the antennas and receivers required to receive information.

There are two stages involved in finding the position of a satellite at a given time:

(a) Calculation of the equatorial crossing time and position for the orbit required;

(b) Extension of this data to the point where the satellite rises above the horizon of the listening station.

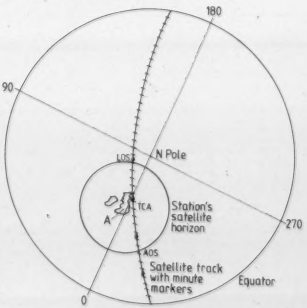
As a satellite travels round the earth, its track makes an angle to the earth's equator known as the satellite's *inclination*, angle I on figure 1. The time at which the satellite crosses the equator when northbound (*ascending node*) is called the *equatorial crossing time* (ECT). The position of this crossing is usually given as degrees of longitude west of the Greenwich meridian. The *orbital period* of a satellite remains fairly constant, although over long periods a reduction in this time becomes apparent as the satellite height falls as a result of drag caused by the very thinly dispersed matter in its path. Each successive orbital track appears to move west by an amount referred to as the *longitudinal increment*, an effect produced largely by the rotation of the earth about its axis.

Signals from the satellite can normally only be heard when the satellite is above the receiving station horizon and one can draw a circle on a map that shows the region the orbit track must enter for the satellite signals to be heard. The size of this circle depends of course on the height of the satellite. The simplest and cheapest way to display orbital tracks is on a polar projection map of the northern hemisphere. Such maps, with transparent plastic overlays for Oscar satellites, are available from AMSAT UK. Figure 2 shows such a map. The orbital track with minute markers is printed on an overlay and is pivoted about the North Pole on the map. The station's satellite horizon is stuck into position on the map with the station location A at its centre.

The satellite can be heard during two sets of orbits during a day—those when the northbound orbits cross the circle and those when southbound orbits come into range about 12 h later.

Starting with a reference orbit, the ECT for an above-horizon orbit is calculated, e.g. Oscar 8 reference orbit for 16 May 1981 (AMSAT UK 1981): orbit number 16286; ECT 1.22.28 GMT at 81.3°W.

Figure 2 Polar projection map for satellite tracking. AOS, time of acquisition of signal; LOS, time of loss of signal; TCA, time of closest approach to station at A



David Anderson Duff *was until recently head of science at Tawd Vale High School, Skelmersdale and is now Science Education Research Officer with Unilab Ltd, Blackburn. He has been a licensed radio amateur since 1967 (G3VYV) and his principal interests revolve around microelectronics.*

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Looking at table 1, Oscar 8 has an orbital period of 1 h 43 min 11.55 s and a longitudinal increment of 25.8°W. Rotation of the track on the map shows that the satellite passes nearest overhead northbound when it crosses the equator at around 350°W. Successive addition of 1 h 43 min 11.55 s and 25.8°W to the reference orbit yields a near overhead pass 10 orbits after the reference orbit: orbit 16296; ECT 18.34.24 GMT at 339.3°W.

Alignment of the start of the overlay track on the map with 339.3°W on the map's equator shows, by counting of minute markers, that the satellite will rise to the south some $7\frac{1}{2}$ min after ECT. So time of acquisition of signal, AOS $\simeq$ 18.42. Its path subsequent to that time can be followed by reference to the map. AMSAT UK overlays are marked also with elevation and azimuth contours which are very useful when pointing a directional antenna.

If, in the case of Oscar 8, the orbital periods and longitudinal increment are multiplied by 14 one finds: 14 × orbital period = 24 h 4 min 41.7 s, i.e. 1 day + 4 min and 41.7 s; 14 × longitudinal increment = 361.2° = 1 full circle + 1.2°. So a day later the satellite will cross the equator 4 min and 41.7 s later and 1.2 degrees further west. By calculating the daily increments for satellites, a great deal of time can be saved. It is useful to note that Oscar 8 and NOAA 6 have similar heights and angles of inclination so an Oscar 8 overlay can be used for NOAA 6. Table 1 gives data for NOAA 6 and for present and planned Oscar satellites.

Antennas for reception

Satellites use either linear polarisation or circular polarisation but for their reception it is best to use a circularly polarised receiving antenna so that the incoming signal is not affected by differences of polarisation between the satellite antenna and the receiving antenna. A linearly polarised antenna can be used but fading will be experienced from time to time unless the receiving antenna is rotated to bring it into line with that on the satellite. There are definite advantages in using a receiving antenna which is directional in nature as this will give gain on the satellite signal and also tend to reduce interference from other sources. The disadvantage is that a directive antenna must be moved to track the satellite.

Table 1 *Satellite data as at 1 June 1981*

	Orbital period /h:min:s	*Orbital increment* /deg long. W	*Inclination* /deg	*Mean height*/km
Oscar 7	1 : 54:56.5	28.737	101.5	1455
Oscar 8	1 : 43:11.55	25.800	98.9	904
UOSAT Phase 3B	1 : 38: 0†	24.5†	97.5†	530
	11 : 01: 0†			
NOAA 6	1 : 41:13	25.304	98.7	815

† Provisional figure

A pupil at Tawd Vale High School, Skelmersdale explains to a group how an orbit presented on a globe can be transferred to a polar projection map

A simple pair of *crossed dipoles* works well for much of a pass when the satellite is well above the horizon. The dipoles must be phased to operate in circular mode and it is usual to phase them to receive clockwise circularly polarised signals. The phasing is achieved by placing a quarter wave 'delay line' to one of the pair of dipoles. This is made from coaxial cable cut to the correct length, bearing in mind the velocity factor of the cable in use. The whole question of antenna design is a complex one which the reader may wish to pursue (see, for example, *The ARRL Antenna Book*, Evans and Jessop 1976, Taggart 1979), however the designs shown in figure 3 have been found to work well.

To calculate the dimensions shown in the diagram, the following formulae can be used:

$$L = 14265/f$$
$$T = P = 4950/f$$
$$S = \text{any equal length}$$
$$H = 6600/f$$

where f is in MHz, L, T, P, S and H are in cm and assume the velocity factor of the cable to be 0.66. A variation of this antenna with improved performance is described by Osborne (1972).

The *helix* is an antenna that can be made from easily obtained materials and is easily constructed (figure 4). It has the advantage that it has a wide bandwidth so one designed for 145 MHz reception of Oscar will also work well with 137 MHz signals from weather satellites. As more turns are added to the helix, the gain and directivity increase. However, there is little point in going above seven turns, and three to five is probably adequate. Again, it is best to opt for clockwise polarisation for reception purposes (i.e.

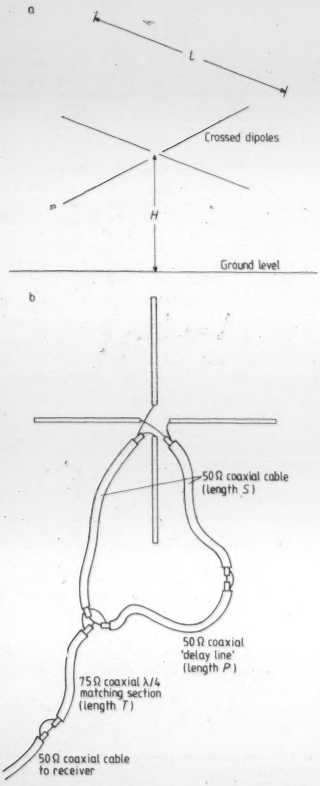


Figure 3 Clockwise polarised crossed dipole for satellite reception. **a,** Side view. **b,** View from above: inner and outer connections to coaxial cables must be as shown for clockwise polarisation

standing behind the antenna, the helix wire is rotating clockwise away from you).

Receivers

If there is a problem in establishing a satellite receiving station, the receiver is likely to be the biggest hurdle and it is wise to tackle this aspect of the project first. The problem is one of cost, but with a little ingenuity this can usually be overcome. Requirements are as follows.

For Oscar 10 m and 2 m transmissions, the receiver must be narrow bandwidth (to reduce noise

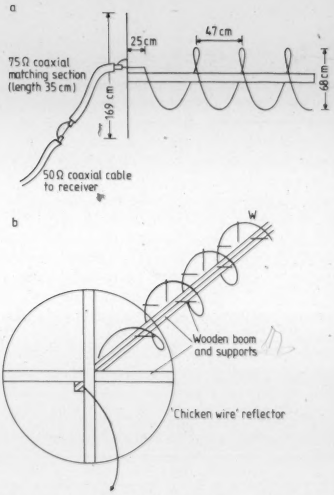


Figure 4 Helix antenna for 137–146 MHz reception. **a,** Side view. **b,** Rear view: W is stiff wire, tubing or stout coaxial cable (inner coaxial cable is connected to outer conductors at both ends)

and adjacent interference), reasonably sensitive and capable of demodulating SSB, CW (Morse) and narrow bandwidth frequency modulated (NBFM) signals. The ideal approach to this is to obtain a 10 m receiver which can demodulate SSB signals and add to it an NBFM demodulator and a 2–10 m converter. The NBFM demodulator only becomes important if you wish to receive signals from UOSAT. A 2–10 m converter will mix any incoming signal in the 2 m band which can be received and demodulated by the 10 m receiver (figure 5).

This approach has the advantage that the equipment can be built up over a period of time, starting with the 10 m receiver for reception of Oscar 8 mode A. Such receivers tend to be very expensive, but some alternatives which might be considered are:

(i) Using of a WD surplus receiver;

(ii) Borrowing a receiver from a colleague or parent or local radio amateur;

(iii) Seeking 'sponsorship' for the project from the PTA or a local industry;

(iv) Using a CB single sideband receiver, made redundant by recent Government legislation. This will need to be modified to cover the 10 m satellite band;

(v) Building a receiver from a kit. Ambit International, which advertises in many electronics

magazines, produces the RX80 receiver in kit or ready-built form. The basic unit needs the addition of the 29–30 MHz converter. An NBFM adaptor is also available. This kit is suitable for those who have some experience in the construction and alignment of receivers. If you do not have such experience, you may either obtain the services of a colleague or contact who has, or alternatively, purchase the units 'ready-built'. Either way, this will be cheaper than purchasing a commercial 10 m receiver. The cost of a kit to build a receiver, 29–30 MHz converter and NBFM adaptor is approximately £71.

If the user wishes to receive 2 m transmissions, then a 2 m converter is required. A reasonably experienced constructor can make one from parts and many designs are featured in the radio amateur press (Evans and Jessop 1976). Alternatively, a ready-built unit can be purchased (e.g. Microwave Modules MMC 144/28).

For *weather satellite reception* in the 137 MHz region the AMBIT 96640 receiver, fitted with crystals for 137.5 and 137.62 MHz reception, is very suitable. Note that the user must request that the unit is supplied with a 50 kHz bandwidth filter as the standard filter has too narrow a bandwidth for use with weather satellites. This receiver is available as a kit for experienced constructors, or ready-built. It is possible to modify some standard broadcast v.h.f. FM receivers for use on the 137 MHz frequencies. A reasonably sensitive, low noise unit will be required and is modified by raising its local oscillator frequency by about 38 MHz then retuning the r.f. input and mixer circuits. Often these changes can be accomplished by the removal of small fixed capacitors from tuned circuits to raise their resonant frequency, then peaking the circuits for optimum performance by means of the tuned circuit trimmers. A stable, low power signal source within the satellite band will be needed for final tuning up.

Using satellite signals

Success in plotting satellite positions and obtaining readable signals is itself extremely interesting. The creation of orbital data is a most challenging and satisfying project. However, care must be taken in the use of AOS and LOS times (acquisition and loss of signal) as these do not necessarily coincide with the point where the satellite crosses the station's horizon circle. At such angles, atmospheric refraction becomes significant. The ionosphere can also play some rather strange tricks. A more reliable fixed point for use in calculations is the time of closest approach (TCA), obtained by Doppler shift measurements as explained later.

To obtain best use of satellite facilities, it is essential to keep up to date with developments. Much useful information is published by AMSAT and the Radio Society of Great Britain. Both of these organisations

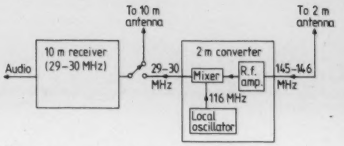


Figure 5 Schematic diagram of 2–10 m converter

supply periodicals to their members and also have a range of other publications of special interest to Oscar and NOAA users.

Examples of satellite based activities

Using Oscar 8 data telemetry: Oscar 8 is used as an example here because it has a relatively simple data frame which can be tried as a practice ground prior to the use of the more comprehensive UOSAT and Phase 3B facilities. It is unlikely that a school will have a person able to decipher Morse code numbers at 20 words/min. However, Morse numbers have a logical code sequence and are easily decipherable if they are recorded at high speed and played back at half or quarter speed.

As explained in part 1, the channel 1 group indicates total solar array current. This channel can be used as 'light meter' to indicate when the satellite is illuminated or in the earth's shadow. When a satellite is first launched and before it has been stabilised, its rate of tumbling can be measured by observation of the cyclic variation in its array output. This occurs because one face of the satellite is not covered by solar cells and a minimum current is obtained when this face is towards the sun. The difference between channels 1 and 2 indicates the current taken by the satellite's circuits, transmitters and receivers. Changes in this level can be related to satellite mode or the amount of activity through the transponders.

Satellite failure is often caused by failure of the rechargeable battery. If channel 3 is monitored over a period of time one can assess trends in the battery's state and try to explain these in relation to the satellite's position and usage. As the earth orbits the sun, there are times when the satellite spends part of its time in darkness but other times when it is illuminated continuously. The latter situation can result in battery overcharging, and therefore overheating. The difference between channels 4 and 5 gives the excess temperature of the battery. Considered alongside readings from channel 3 one can build up a picture of battery state which can be related to considerations on the craft's usage and attitude to sun and earth. When battery overcharging is anticipated, the satellite may be put into modes A and J simultaneously, a point that can be established

if the reading on channel 6 is other than '601' when the mode A transponder is in operation.

Doppler shift is very noticeable on satellite signals, particularly on the higher frequency transmissions. As the satellite nears the position of closest approach, its velocity relative to the observer is falling and the frequency of an onboard beacon will gradually fall at an increasing rate to its nominal value. As the satellite moves away, the received frequency will continue to fall and at a decreasing rate. This effect has several uses:

(i) It can be used to determine the velocity of the satellite;

(ii) The time of closest approach can be determined, using either the point where the beacon is heard on its nominal frequency or the point where the rate of change of received frequency is at a maximum.

(iii) It produces an illustration of Doppler shift in EM waves.

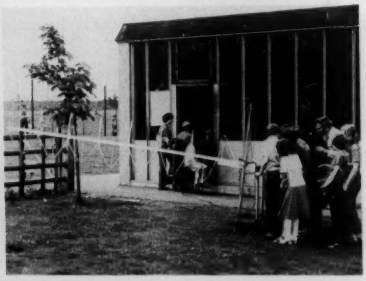
For any quantitative work on this effect, one needs a stable receiver. The amount of shift can be measured by beating an audio signal generator against the audio tone from the receiver and plotting audio generator frequency against time. Formulae for relative velocities and Doppler shifts will be familiar to the reader.

Finally, pulsed signals of the type permitted by the amateur licence can be used by licensees through the transponder for *satellite ranging*, and *creation or updating of satellite orbital information* can be achieved by careful observations on AOS and LOS times or, preferably, by measurement of TCA.

Weather pictures

Obtaining weather pictures from weather satellites is not as hard to achieve as might be imagined. Pressure of space precludes great detail here but much of quality has already been written (Osborne 1971 and Taggart 1979 give relatively simple circuits). The simplest method for a school to use is to create the picture on an oscilloscope tube, line by line as it is received, and use a camera with an open shutter to sum the lines into a full picture. The audio output from the receiver is used to 'z' modulate the spot brightness whilst a fast integrator, locked to the satellite line sync., produces the line scan. At the same time, a slower integrator produces the necessary frame scan. UOSAT will use a rather different means to transmit its pictures of earth. The information will be sent digitally, each picture consisting of a frame of 256 by 256 pixels, each pixel having 16 possible grey tone levels. Digital techniques will therefore be needed to interpret the data.

Pupils and staff at Tawd Vale High School, Skelmersdale with the seven-turn helix await the arrival of the satellite. This orbit was a 'Just left of the tennis courts' pass!



Using the school computer

Many aspects of satellite work lend themselves well to assistance granted by the use of a computer. Many orbital calculations are long and repetitive but can be coped with easily by a computer or programmable calculator. The extent to which this facility is used will depend on the user's programming skills. Some ideas that might be considered:

(i) Calculating ECTs and corresponding longitude west positions.

(ii) Continuous real-time readout of satellite azimuth and elevation, perhaps supported by graphics.

(iii) Those interested in computer control might consider linking the information derived from (ii) into an antenna tracking mechanism that moves a directional antenna to follow the satellite.

(iv) Using the computer to store orbital information about several satellites then using its internal clock to give advanced warning of impending orbits that come within range of the receiving station.

(v) Using the computer to decode and store data received from the data beacons.

(vi) Displaying UOSAT pictures using a high definition graphics computer and a machine code program.

(vii) Using a Morse reading program to read the Morse code on the data beacons.

Many of these ideas require the use of interface units external to the computer.

Whilst these two articles can only touch the surface of such a wide ranging topic, I hope they will encourage more teachers and students to listen to and make use of the information available from inner space.

Acknowledgment

The author wishes to extend grateful thanks to the following who have assisted either in the production

of these articles or in his satellite project at Tawd Vale High School : NASA Goddard Space Flight Center, USA; Dr M N Sweeting, Surrey University; Mr R Broadbent, Secretary AMSAT UK; and the staff and pupils of Tawd Vale High School, Skelmersdale.

Postscript

UOSAT was successfully launched in November 1981. The details are as follows: orbital period, 1: 35: 21.2; orbital increment, 23.8765°; inclination, 97.462°; 2 m transmission *anti*clockwise polarisation (the antennas for Oscar 8 and NOAA satellites are clockwise polarised).

Also Oscar 8 now seems to have failed after very long service.

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Tops—with strings attached

M J Lea

In a recent *Horizon* programme (BBC2, 26 January 1981) Professor Laithwaite again suggested that gyroscopes do not follow Newton's laws of motion. In particular he implied that a spinning gyroscope, or top, precessing about a pivotal support tower (figure 1a) produces no horizontal radial force F on the pivot. Consequently, even if the tower were standing on an absolutely frictionless surface, the top would precess round the stationary tower as shown. But Newton's second law requires that a mass m moving in a circle of radius r with angular velocity ω ($= 2\pi/T$ where T is the precession period) experiences a centripetal force $F = mr\omega^2$ and hence there must be an equal and opposite outward, or centrifugal, reaction force on the pivot. In this case, on a frictionless surface, the tower would precess round the stationary centre of mass of the top (figure 1b) with $r = 0$.

To distinguish between these predictions the *Horizon* programme showed two experiments. In the first (from Professor Laithwaite's Christmas lectures at the Royal Institution in 1978) the tower was placed on ice and did not move as the top precessed round it. Hence $F = 0$—or is it? The second experiment, by the *Horizon* team, showed a moving tower on a raft of ball bearings, supporting Newton's laws. This particular demonstration is difficult as the forces involved are small. For a 1 kg top precessing every 6 s

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on a circle of radius 0.1 m the centrifugal force on the tower would be only 10 g weight. Hence a coefficient of friction greater than 0.01 (a very small value) between the tower and the surface would also prevent the tower moving as the top precessed round it.

On the principle that these forces have to be *felt* to be believed, I would like to describe a simple, yet dramatic, experiment with interesting results which can be easily analysed. Simply suspend a spinning gyroscope, or top, from a string whose length l can be varied, and set it precessing with the axis horizontal. For a given angular precession frequency ω, the configuration of the top depends on the length of the string. For a short string the top precesses pointing outwards (figure 2a) and the impression gained is of the string pulling the top round in a circle. For a long string, however, it points inwards (figure 2b) and the top seems to pull the string round. If the length is changed by holding the string it is found that the radius of the precession circle depends strongly on l; for a critical length the top veers wildly in a large circle and the spinning axis tilts rapidly. This behaviour is seen both as l is increased and decreased to the critical value. The centrifugal forces produced by the precessing top on the human pivot are then considerable and leave one in no doubt of their existence!

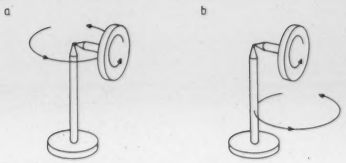

Figure 1 Spinning top precessing round pivot which is **a**, fixed or **b**, free to move on a frictionless surface

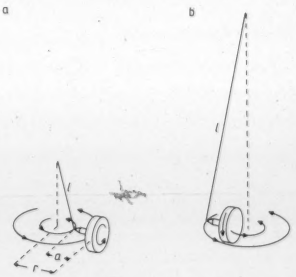

Figure 2 Spinning top precessing round a suspension string showing observed configurations for **a**, short string and **b**, long string. Centre of mass precesses in a circle radius r. The (fixed) distance between the centre of mass and the point of support is a

Analysis

To analyse this behaviour, note first that if F were zero then the top would precess freely about a *vertical* string of any length, corresponding to the situation in figure 1a. Following Newton's laws, the only forces on the top are the weight mg and the tension in the string. For precession of the centre of mass in a horizontal circle of radius r the vertical component of the tension must just balance the weight (the unbalanced torque mga from these forces drives the free precession of the top). If the string makes only a small angle to the vertical the tension may be taken as equal to mg and its horizontal component is then $mg(r-a)/l$. Equating this to the centripetal force $mr\omega^2$ we find

$$r = \frac{a}{1 - \omega^2 l/g}$$

For a short string, with l small relative to ω^2/g, $r \approx a(1 + \omega^2 l/g)$ and the precession configuration is as observed and shown in figure 2a. In the limit $l = 0$ this corresponds to a *fixed* pivot (figure 1a). For a very long string, $r \approx -ag/\omega^2 l$ and the top precesses round a point near the centre of mass as observed and shown in figure 2b. This corresponds closely to a *frictionless* pivot (figure 1b), confirming the result using ball bearings. The critical length l_c is easily understood as the precession angular frequency ω then equals the natural angular frequency of a pendulum of length l_c, namely $(g/l_c)^{1/2}$. r then increases rapidly as given by the equation and as observed experimentally. The simple theory would predict an infinite r but the various assumptions made (e.g. small angles, horizontal top) become invalid and singularities of this sort are unfortunately avoided! In practice a top precessing with a period of about 2 s is convenient as the length of a pendulum with the same period is about 1 m and both the introvert (long string) and extrovert (short string) modes of precession can be demonstrated.

Never mind the maths—feel the force!

Materials posters

Two full-colour posters have been produced on the theme of metallurgy and materials technology. The posters are intended for use at careers conventions and can be obtained from the Assistant Secretary (Education), The Institution of Metallurgists, Northway House, High Road, Whetstone, London N20 9LW (tel. 01-446 2251).

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The case of the disappointing tuned circuit

E M Wray

Many first-year university physics students carry out a simple experiment on an electrical tuned circuit. They connect a coil and capacitor in series to an audio oscillator of low source impedance and then study how the current varies with frequency. They detect the resonance and plot the well known resonance curve which they find, usually, to be very broad and asymmetrical.

The disappointment comes when they measure the sharpness of the resonance and obtain a value for the quality factor Q of the circuit. This is usually depressingly small, quite often less than 10, and far smaller than the value predicted by any of the well known expressions such as $Q = 1/\omega CR$. Even when the source impedance of the oscillator is allowed for, there usually remains a yawning gap between experiment and theory. A knowledgeable student may talk, with much hand-waving, about the skin effect, but the frequencies used in these elementary experiments are usually far too low for this to be a significant factor. So the puzzle remains.

During a discussion of this problem, my attention was drawn to the book *Soft Ferrites* by E C Snelling (1969). This contains a wealth of information on the winding of high-Q coils with ferrite cores, and includes an account of the 'proximity effect'. Whereas the skin effect arises from the eddy currents produced in a conductor by the alternating current it is itself carrying, the proximity effect arises from eddy currents produced by currents in neighbouring conductors. This effect can be very large when several hundred turns of wire are wound in close proximity—hence the name.

The proximity effect provides the answer to the puzzle. The eddy currents produce a power loss in the coil and thus, in effect, increase its resistance. This increase broadens the resonance peak of the tuned circuit and lowers the Q value. This article shows how the resistance arising from the proximity effect may be estimated, how it may be measured and how a coil can be designed that is largely free from this effect at audio frequencies.

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Calculation of the proximity effect

We first find the power loss due to eddy currents induced in a single long straight wire by an external magnetic field. Snelling gives a derivation for a wire of rectangular cross section; we apply the same method to a wire of circular cross section.

Figure 1 shows a wire of length l and diameter d, with a magnetic field $B = B_0 \sin \omega t$ passing perpendicularly through it. We can imagine the wire to be composed of a large number of rectangular sheaths, around which the eddy currents flow. Figure 1 shows one of these sheaths. Its overall dimensions are $l \times 2y \times 2x$; its thickness is dx. The sheath presents an area $2lx$ to the magnetic field, so that the e.m.f. induced in it is

$$E = 2lx(\mathrm{d}B/\mathrm{d}t)$$

This has a peak value

$$E_0 = 2\omega lxB_0$$

The perimeter of the sheath (neglecting the short sides) is $2l$ and the area presented to eddy current flow is $2y\mathrm{d}x$. The resistance of the sheath is thus

$$R = \rho l/y\mathrm{d}x$$

where ρ is the resistivity of the wire.

The mean power dissipated in the sheath by eddy currents is

$$\begin{aligned} \mathrm{d}P &= E_0^2/2R \\ &= 2\omega^2 B_0^2 lx^2 y\mathrm{d}x/\rho \end{aligned}$$

Integrating for all sheaths, we have for the total power loss due to eddy currents

$$P = \frac{2\,\omega^2 B_0^2 l}{\rho} \int_0^{d/2} x^2\, y\mathrm{d}x$$

The integral may be evaluated by expressing x and y in terms of the angle θ and the diameter d (figure 1), and yields the result

$$P = \pi\, \omega^2 B_0^2 l d^4/128\rho \qquad (1)$$

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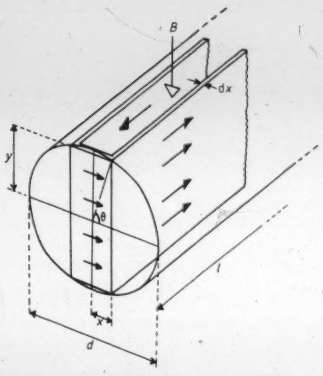


Figure 1 Eddy current induced by a magnetic field in arectangular sheath element of a long straight wire

Equation (1) is a general result for any long cylindrical conductor. The only assumption that has been made is that the frequency is not high enough for the eddy currents themselves to be subject to the skin effect. There is no significant skin effect in wires less than 1 mm in diameter at audio frequencies (Snelling 1969 p343).

We now imagine the wire to be wound into an air-cored coil of N turns, each carrying an alternating current $I = I_0 \sin \omega t$. The magnetic field is now produced by this current. Each turn contributes a component to the field B_0, and also experiences a resultant B_0 due to its neighbours that varies from place to place in the winding. Our problem is to find an average value of ${B_0}^2$ across the whole winding to substitute into equation (1). This is a difficult problem with no exact solution. However, an approximate solution can be found quite easily if we are prepared to make three assumptions, two of them quite modest. The first is that the winding cross sectional area is circular (instead of the usual rectangular shape). The second is that the total current NI is distributed uniformly across this area.

The third, less modest assumption is that if the diameter of the coil is much larger than the thickness of the winding we can treat the winding as a long straight conductor. This is obviously a very poor assumption if we wish to find the field at any distance from the winding, but is not too unreasonable if we are concerned with the field within the winding itself.

If, now, the winding has a radius a and carries a current NI, then the field at a radius r within the winding is found by Ampère's law to be

$$B = \mu_0 NIr/2\pi a^2 \qquad (2)$$

This field is experienced by all those turns which pass through an annulus of radius r and width dr. The total length of these turns is found from the ratio of the area of this annulus to the total cross sectional area: it is

$$l \times 2\pi r dr/\pi a^2 \qquad (3)$$

Combining equations (2) and (3) gives the term ${B_0}^2 l$ in equation (1) for the annulus as

$$\mu_0{}^2 N^2 {I_0}^2 l\, r^3\, dr/2\pi^2 a^6$$

where I_0 is now the peak current. Integrating over the radius, we have for all the turns in the winding

$${B_0}^2 l = \mu_0{}^2 N^2 {I_0}^2 l/8\pi^2 a^2$$

On substituting this result into equation (1), we find that the mean power dissipated by eddy currents in the coil is

$$P = \mu_0{}^2 N^2 {I_0}^2 \omega^2 d^4 l/1024\pi a^2 \rho$$

We can think of this power loss as being produced by a 'proximity effect resistance' R_{pe}, where $P = {I_0}^2 R_{pe}/2$. Then

$$R_{pe} = \mu_0{}^2 N^2 \omega^2 d^4\, l/512\pi a^2 \rho$$

Finally, we substitute the winding cross sectional area A for πa^2, $2\pi f$ for ω, $1.78 \times 10^{-8}\ \Omega$m for ρ (the resistivity of copper at 20°C), and $4\pi \times 10^{-7}$ for μ_0. The effective resistance is then

$$R_{pe} = 6.8 \times 10^{-6} f^2 N^2 d^4 l/A \qquad (4)$$

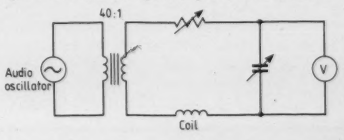
where all the algebraic terms are to be expressed in SI units and R_{pe} is then in ohms.

The most important feature of this result is that the proximity effect resistance increases as the square of the frequency. At high frequencies, however, the eddy currents are subject to the skin effect which reduces the frequency dependence. A frequency-dependent factor can be included in equation (1) to allow for this (Snelling 1969 p345).

Measurements and comparisons

If the additional resistance displayed by coils in audio tuned circuits is due to the proximity effect, then, from equation (4), we should expect it to increase as the square of the frequency. A simple way to test this is to measure the resistance of a series tuned circuit at resonance at various frequencies. Figure 2 shows the

Figure 2 Circuit used for proximity effect measurements



circuit that was used to do this. The resonance was detected by a high impedance valve voltmeter connected across the capacitor. At resonance the circuit is purely resistive and the quality factor Q is then equal to V_c/V, where V_c and V are the magnitudes of the voltage developed across the capacitor and the applied voltage respectively. We can also express Q as $1/\omega CR$, where R is the total effective resistance in the circuit. Thus, at resonance,

$$V_c = V/\omega CR$$

The resistance R was measured by adding an additional series resistance (by means of a decade resistance box) sufficient to halve V_c. Then, if V is constant, the added resistance is equal to R.

The main contributions to R are the d.c. resistance R_{dc} and the additional resistance R_a of the coil. The contribution of the voltage source was reduced by inserting a 40:1 stepdown transformer between the oscillator, of 600 Ω output resistance, and the tuned circuit. If the transformer were ideal, this would reduce the source resistance by a factor of $(40)^2$ to less than 0.4 Ω. The actual source resistance was found to be 0.6 Ω at 10 kHz, rising to 1.6 Ω at 50 kHz. For most of the measurements made, this is small enough to be ignored and to ensure that the applied voltage V is independent of the total resistance of the circuit.

Dielectric losses in the capacitor will also contribute to R through an effective series resistance r, which is usually expressed in terms of a dissipation factor ωCr. For the JJ Instruments decade capacitance box type C4 used in these measurements, a maximum dissipation factor of 10^{-3} is quoted. This gives values of r that are usually less than 1 Ω in the audio frequency range, again small enough to be ignored.

Measurements were made on five air-cored coils with inductances ranging from 10 to 156 mH. For each coil the total resistance R was measured at several frequencies in the range 1–50 kHz. The d.c. resistance was then subtracted to give the additional resistance R_a.

For each coil R_a was found to vary as the square of the frequency; figure 3 shows logarithmic plots for two of the coils. Results for all five coils are summarised in table 1, with measured values of R_a at 10 kHz, obtained graphically, listed against values of R_{pe}, calculated from equation (4). In each case R_{pe} is less than R_a, the average discrepancy being about 40%.

It seems clear, therefore, that the additional resistance observed in coils at audio frequencies is indeed due to the proximity effect and that its magnitude can be estimated to within a factor of about two or three. Equation (4) seems to be valid even for small coils, such as the 10 mH sample, for which the initial assumption, that the overall coil diameter is much larger than the winding thickness, is certainly not true.

Eliminating the proximity effect

For introductory experiments on tuned circuits, it is obviously preferable to use a coil whose performance can be accurately predicted by the simple theory of resonance. One approach is to abandon air-cored coils altogether and to obtain inductances in the range 10–100 mH by winding coils on small ferrite cores. It is indeed easy to produce coils with Q values of well over 100 at 10 kHz by using modern cores and bobbins. Because the number of turns N and total length of wire l are small, the proximity effect in such coils is almost negligible. Unfortunately, the ferrite core itself exhibits losses that vary not only with frequency but also with the amplitude of the resonance.

One such coil was made by winding 400 turns of 34 SWG wire on a Radiospares RM10 bobbin. Its inductance was 100 mH and its d.c. resistance was 8.6 Ω. Its predicted R_{pe} was less than an ohm. However, its total resistance was found to be 18 Ω at 5 kHz, rising to 40 Ω at 15 kHz. When the ferrite was removed, the inductance fell to 2 mH and the total resistance at 15 kHz to 9 Ω, indicating that the ferrite was responsible for all the extra resistance and that R_{pe} was, as calculated, negligible.

One technique that has been used to reduce the proximity effect in air-cored coils is to increase the cross sectional area A of the winding by introducing spacings between each turn and each layer. Such a

Figure 3 Additional resistance versus frequency for 100 mH coil (left-hand plot and scale) and 10 mH coil (right-hand plot and scale). Circles give values of R_a; lines give R_{pe} from equation (4)

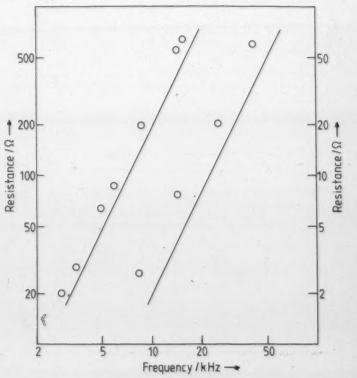


Table 1 *Summary of measurements on five coils*

Inductance/mH	*Outer diameter*/cm	*Number of turns*	R_{dc}/Ω	R_x *at 10 kHz*/Ω	R_{pe} *at 10 kHz*/Ω
10	3.5	700	14.4	3.6	2.0
50	14	670	8.2	85	59
85	23	500	9.3	85	50
100	10	1030	8.8	240	190
156	39	500	14.7	230	88

coil is, however, very awkward to make. Another technique is to use Litz wire, which consists of many fine insulated strands. The individual strand diameter is now substituted for d in equation (4), and this reduces R_{pe} considerably. Unfortunately, Litz wire is now very hard to find.

However, a conventional close-wound air-cored coil may be designed, for which the proximity effect produces a negligible increase in resistance. Harris (1957) states that the optimum air-cored coil (maximum inductance for minimum quantity of wire) has a square winding cross section of side b and an inner diameter of $2b$. The inductance of such a coil of N turns is

$$L = 24.5 \times 10^{-7}\, bN^2$$

where L is in henries and b is in metres. If one turn of wire, diameter d, occupies an area d^2 in the winding, and the whole winding area b^2 is filled with N turns in a simple square packing, then $b^2 = Nd^2$. (This neglects the insulation thickness of the wire.) Then

$$L = 24.5 \times 10^{-7}\, b^5/d^4 \qquad (5)$$

As the mean diameter of the winding is $3b$, the total length of wire l is $N \times \pi 3b$. Combining this with the cross sectional area of the wire and the resistivity of copper, we obtain the d.c. resistance of the winding as

$$R_{dc} = 2.1 \times 10^{-7}\, b^3/d^4 \qquad (6)$$

where, again, b and d are in metres and R_{dc} is in ohms.

The proximity effect resistance (Ω) is found by substituting for N, l and A in equation (4). The result is

$$R_{pe} = 6.4 \times 10^{-5}\, f^2\, b^5/d^2 \qquad (7)$$

Suppose now we wish R_{pe} to be significantly less than R_{dc}. Let us say we require $R_{pe} = 0.1\, R_{dc}$ at 10 kHz. Substituting this condition into equations (6) and (7) gives

$$b^2d^2 = 3.3 \times 10^{-12} \qquad (8)$$

If we combine equations (8) and (5) to eliminate d, we have the following curious 'high-power' result relating the inductance of the coil (H) to its size

$$L = 2.25 \times 10^{17}\, b^9 \qquad (9)$$

Thus, from equation (9), a coil of 10 mH inductance should have $b = 7.1$ mm, that is, a length of 7.1 mm, an inner diameter of 14.2 mm, and an outer diameter of 28.4 mm. Equation (8) then gives the wire diameter as 0.26 mm; there should then be 770 turns. From equation (6), the expected d.c. resistance will be 18 Ω, and the Q factor at 10 kHz (given by $\omega L/R_{dc}$) should be 35. For a coil of 100 mH, we find $b = 9.1$ mm, wire diameter = 0.20 mm, number of turns = 2100, R_{dc} = 100 Ω and an expected Q at 10 kHz of 63.

A 10 mH coil was wound according to the above specifications. A bobbin was made from tufnol rod, padded out to the right diameter with paper tape, and fitted with perspex end-pieces. 34 SWG enamelled wire, of diameter 0.23 mm, was chosen for the winding, 700 turns being found sufficient for an inductance of 10 mH. The d.c. resistance was found to be 19.3 Ω. The proximity effect resistance was recalculated, using the actual dimensions of the finished coil, and came to 0.9 Ω at 10 kHz. The corresponding measured value, obtained as before by graphical extrapolation from results at higher frequencies, was about 1.5 Ω. Thus equation (4) again produces a value for R_{pe} that is about 40% low.

For all normal uses this coil is very mediocre, giving in a tuned circuit a resonance peak about 300 Hz wide at audio frequencies, but in an experiment in a teaching laboratory this is not such a disadvantage. The careful student, at least, should no longer be disappointed with his or her results!

Acknowledgment

I would like to thank Dr P C Riedi for drawing my attention to the proximity effect and to the book by Snelling.

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SOFTWARE ROUNDUP

This is the first of a series of occasional lists of computer programs available for physics teaching. We acknowledge with gratitude the permission of *Educational Computing* to reproduce this material, which appeared in that magazine towards the end of 1980.

We would be glad if readers as well as software suppliers would draw our attention to other physics education programs for popular hardware. It is our intention to review new material of this nature in the future. Readers interested in reviewing physics programs for *Physics Education* are invited to contact the Staff Editor at the address given at the front of the magazine.

Language codes

B BASIC F FORTRAN

Supplier codes

A Arnold, Woodlands Park Avenue, Maidenhead, Berks (handles Chelsea and other programs)
C Commodore—contact local dealer
CPE Central Program Exchange, Polytechnic, Wulfruna Street, Wolverhampton (club)
D Databank, 66 Queens Road, Loughborough
H Huntingdon Computer Projects, SUNY, Stonybrook, New York
M Muse, Freepost, Bromsgrove, Worcs B61 0JT (professional association)
MA Microcomputer Applications, 11 Riverside Court, Caversham, Reading
O Ohio Scientific (contact local dealer)
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S Softech, 17 Knockcullen Park, Dublin 16

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A Apple
I ITT 2020
O Ohio
P Pet (Commodore)
PDP DEC PDP11
S SWTPC
So Sorceror
T Tandy TRS80

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LEE'S DISC	CPE	B	"	Simulation	A	£1.00
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ELECTRONICS 1	D	B	"	Ohm, power, reactance	?	£5.00
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SLITS	H	B	PDP	Young	A	£5.00
SCATR	H	B	"	Rutherford	A	£5.00
CHARGE	H	B	"	Millikan	A	£5.00
SIMULATIONS 1	H	B	"	Electricity, magnetism, atoms	?	?
AUFBAU	M	B	S	Electrons in energy levels	A	£0.50
DOPPLER	M	B	"	Demonstration	A	£0.50
ELECTRONICS ASSISTANT	MA	B	T	?	?	£6.00
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Discovering electrical equivalent circuits

S Waks

Teachers of electronics are frequently faced with the dilemma of emphasis on inquiry-based instruction versus emphasis on knowledge acquisition teaching. Meaningful learning is more efficient than rote learning (Ausubel 1969) but imparting large amounts of factual information raises problems of uptake and retention. This is an acute problem, especially in our era of information explosion.

Discovery or inquiry instruction is one way to enhance the meaningfulness of learning a particular subject (Waks and Silberstein 1978). This article presents a suggestion for imparting the equivalent circuit concept via a guided inquiry route, with the student developing and eventually 'identifying' the equivalent circuits of electronic devices such as diodes and transistors, according to given input and output characteristics of these devices.

The equivalent-circuit concept comes into its own in the context of three-terminal devices: the voltage between the collector and the emitter of a transistor in the active region cannot be expressed simply as a product of current and resistance, but calls for the exponential function approach as outlined e.g. by Ebers and Moll (1954), and as such cannot be satisfactorily presented at secondary school level. However, the student is familiar at this stage with networks for which Ohm's law is valid—for instance, a d.c. circuit consisting exclusively of resistive components, conductors and voltage or current sources. Perhaps it could be used in modelling amplifying devices like bipolar or field effect transistors?

Concept of equivalent circuit—passive case

The practice of describing an electrical device through its current–voltage characteristic is also feasible for an electrical circuit, via any pair of its nodes. A circuit like that shown in figure 1a may serve as an introductory example using Thevenin's theorem. The equivalent circuit and characteristic are shown in figures 1b and 1c respectively, the equivalence stemming from the fact that, under given load R_L, the current I is the same in both cases. The student should be induced to arrive, through inquiry, at the conclusion that the reciprocal slope $\Delta U_2/\Delta I$ represents the internal resistance of the network (the

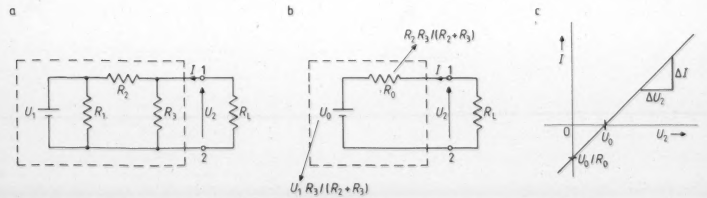
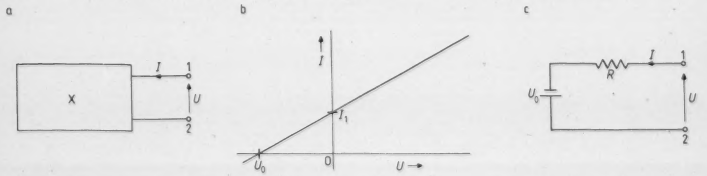


Figure 1 **a**, Example of electrical circuit with **b**, its equivalent circuit and **c**, its current–voltage characteristic

Figure 2 **a**, Circuit identified on the basis of **b**, its current–voltage characteristic and **c**, its equivalent circuit



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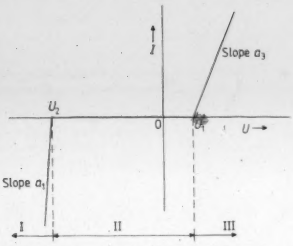

Figure 3 Piecewise linear characteristic of electronics device

dashed boxes), while the intercept on the voltage axis of the characteristic represents the open circuit voltage U_0.

At this stage the student is required to identify the circuits 'belonging' to given current–voltage characteristics.

Example 1: The given characteristic is as shown in figure 2b. The reciprocal slope of the characteristic and then the open circuit voltage (U_0) yield the internal resistance R of the sought circuit, which is shown in figure 2c.

Example 2: Where a nonlinear electronic device is characterised by a piecewise-linear approximation (figure 3), the relevant equivalent circuit has to be determined for each interval I, II and III, as shown in figure 4.

This approach of identifying unknown electronic devices through inquiry can be extended to problems where the characteristic is not given in advance. In such cases the latter is determined, for example, on an oscilloscope—in other words, the device is identified experimentally. This approach has been applied by the author in the self-instruction manual published (in Hebrew) by Everyman's University of Israel (1977).

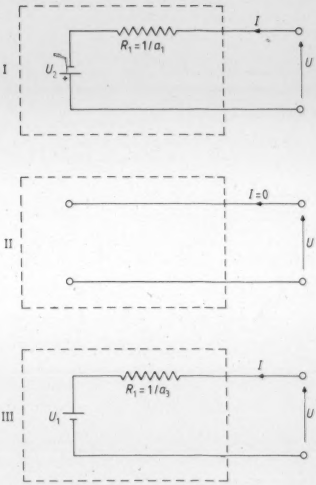

Figure 4 Partial equivalent circuits for intervals I, II and III of device shown in figure 3

Equivalent circuit for active linear region

Having mastered the treatment of passive (two-port) devices, the student can proceed to a transistor (with, it is assumed, familiar output characteristics) in its active linear region, for example the interval AB of the uppermost curve ($U_{GS} = 0$ V in figure 5a). The internal resistance of the circuit is determined from the slope of the curve which is extremely flat in this case—indicating high internal resistance in which context the student should consider whether the source ought to be a current or a voltage. The equivalent circuit is shown in figure 5c. Analogous equivalent circuits are obtainable for the corresponding intervals on the other curves, which represent progressively higher gate–source voltages. The general equivalent circuit is also similar to that of figure 5c; since the gate–source junction is reverse-biased, the gate current is very low and the input resistance very large, so that no resistance is required to be indicated between the gate and the source terminals. The same procedure can be used for other amplifying electronic devices, such as bipolar transistors.

To sum up, the above is an illustration of the possibilities of the guided-inquiry approach in

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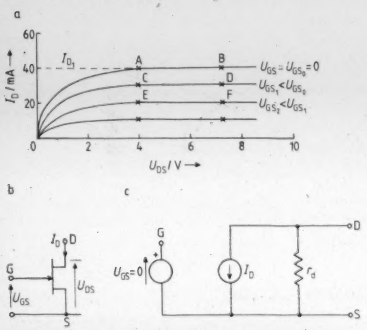

Figure 5 Output characteristics of **a**, field effect transistor and **b**, drain current versus drain–source voltage, with gate–source voltage as parameter. **c**, Equivalent circuit of field effect transistor for interval AB on uppermost curve in **a**

presenting the concept of equivalent circuits. We have found that this approach makes for better mastery and retention of the subject matter.

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Physics of sailing

The physics of sailing is the subject of a half-day meeting in Southampton on 20 January. Factors influencing yacht design will be described by J E Wellicombe of Southampton University, followed by a visit to the ship tank and the wind tunnel in which sails are tested. A number of sixth-form girls will be present to discuss their Insight 81 project which involved water transport. The meeting is being organised by the Education Group of The Institute of Physics and the Southern Science and Technology Forum. Further information can be obtained from the Meetings Officer, The Institute of Physics, 47 Belgrave Square, London SW1X 8QX (tel. 01-235 6111).

PHYSICS IN INDUSTRY

Devices for optical communication systems

M J Robertson

Optical communication systems are at present undergoing very rapid development, with ideas generated from basic research leading to installed systems in only a few years. The main advantages over conventional wire-based transmission are in the small diameter of the fibre cable required, its light weight and the low loss achievable. For example in the current UK intercity telephone network, repeaters (amplifiers) have to be buried every 2 km along the cable route. Not only are these expensive to install and maintain but they consume power. With optical fibres it is hoped to increase repeater spacing to ~ 30 km, because losses are so low.

The basic optical system contains three parts: a source, a fibre and a detector. The source is either a semiconductor laser or light emitting diode (LED). There are three basic types of fibre and two commonly used detectors, the PIN diode and the avalanche photodetector (APD). In most optical systems, information is sent digitally in pulse form, pulses of '1' and '0' (or on and off) forming a binary code. As there are only two choices of value for a pulse, the signal may be sent without the addition of any noise (unlike more conventional analogue systems). Obviously the rate of information transfer (bit rate) will depend on the pulse length—the shorter it is the greater the bandwidth. However, there are limitations imposed by source and detector capacitance, fibre dispersion and noise. In what follows the principles of operation are discussed and

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the ways in which design influences performance will be described.

Fibres

The characteristics of fibres dictate the optimum type of source and detector. There are three basic types of optical fibre, known as step-index, graded-index and monomode. In all three cases a glass central core is surrounded by a concentric glass cladding of slightly lower refractive index. According to Snell's law light in the core impinging on the core–cladding interface with angle of incidence θ greater than θ_c will be totally internally reflected, where

$$\sin\theta_c = n_2/n_1$$

Here n_2 is the refractive index of the cladding and n_1 is the refractive index of the core. Such light is said to be guided by the fibre. If the end face of the fibre is perpendicular to the axis, then the maximum angle of incidence from air for guiding α is given by

$$\sin\alpha = n_1 \sin(90 - \theta_c)$$

$\sin\alpha$ is defined to be the numerical aperture (NA) of the fibre.

In spite of the guiding properties of optical fibres, there will be loss of signal due to scattering and absorption. One of the main absorption centres in silica is the OH^- ion. There are, however, minima in the absorption at wavelengths of 0.85, 1.3 and 1.55 μm. In early work on fibres the loss at 0.85 μm was found to be least, and as this corresponds to the wavelength of GaAs lasers and LEDs, systems were designed at this wavelength (losses $\sim$ 2 dB km^{-1}—a drop of 3 dB corresponds to a loss of 50%). As the silica has been made purer, the losses at 1.3 and 1.55 μm have been reduced until now at 1.55 μm losses of 0.2 dB km^{-1} have been achieved.

Dispersion also limits fibre length, by smoothing out initially square pulses and running adjacent ones into each other, thus degrading information content. There are basically two types, modal and material. The former results from the different optical pathlength that light entering on-axis will travel compared with light entering at an angle (because of multiple reflections). Their different paths are known as modes. Clearly a pulse of light in an axial mode will arrive at the detector before that in an angular mode.

Material dispersion is simply the reason why a prism splits up white light into a spectrum. Light of different wavelengths in the source bandwidth travels at different velocities and arrives at the detector at different times. This dispersion actually goes through zero around 1.3 μm.

Modal dispersion is reduced in graded-index fibre, where the refractive index of the core varies parabolically from a maximum in the centre to a minimum at the cladding. As the velocity of light is inversely proportional to the refractive index, the off-axis rays travel faster to compensate for their longer paths, and different modes arrive at the end together. Non-uniformities in the fibre profile limit the performance of this technique but dispersion is between 20 and 100 times less than for a step-index fibre. In the monomode fibre the diameter of the core is made so small (5–10 μm) that only one (the axial) mode can propagate. This immediately eliminates modal dispersion, but makes alignment and coupling of source into fibre very critical, and so this type of fibre is only used with lasers, which generally have small source dimensions, $\sim$5 μm diameter and narrow linewidth.

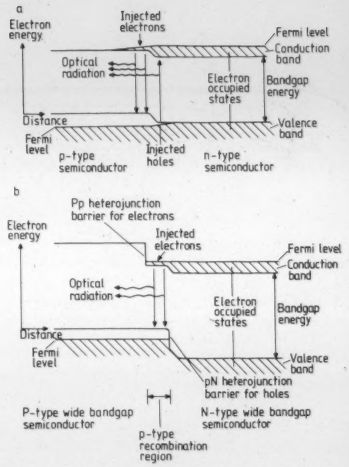

Figure 1 **a**, Radiative recombination of injected carriers in a pn junction and **b**, confinement of injected carriers in a double heterostructure junction

Sources

As previously mentioned, the two types of source used are the laser and the LED. In order to make either, a direct bandgap semiconductor is required, i.e. one where an electron in the conduction band may recombine with a hole in the valence band with the emission of light without the presence of another particle (actually a phonon—a lattice vibration quantum) to conserve momentum. If a third particle (phonon) has to be involved in the collision, it makes the probability of a radiative recombination (emission of a photon) very low, and nonradiative recombi-

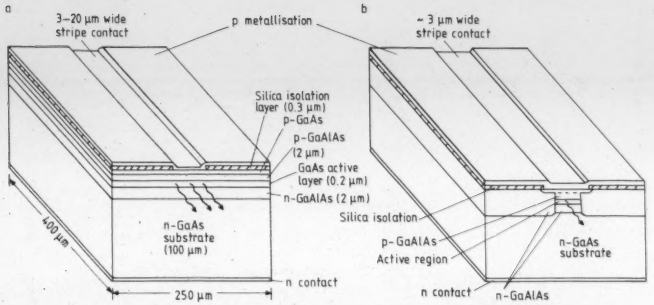

Figure 2 **a**, Schematic diagram of an oxide isolated laser. **b**, Schematic diagram of a buried heterostructure laser

nation (recombination through an impurity or defect centre) much higher. Silicon and germanium are indirect gap semiconductors, while GaAs and InP and their quaternary compounds have direct bandgaps.

In an LED or laser, light is emitted when minority carriers injected through a forward biased pn junction recombine radiatively (see figure 1a). Thus most light is produced in the vicinity of the junction, although some electrons will diffuse away before recombining and may then do so nonradiatively. This light is known as spontaneous emission. If the density of emitted photons is very high then they will interact. When this occurs one photon will initiate electron–hole recombination and the photons produced in this multiplication process will have identical wavelength, phase and direction to the first one. This is referred to as stimulated emission and demonstrates optical amplification, which is necessary for lasing to occur.

To attain lasing conditions a very high density of excess carriers is required in the vicinity of the pn junction. This is accomplished by use of a double heterostructure as in figure 1b. By using layers of a higher bandgap material ($Ga_{0.7}Al_{0.3}As$) with GaAs, potential barriers are presented to the minority carriers, confining them to the so called active region. The choice of material for the confining (passive) layers is critical. It must be possible to grow the whole structure as a perfect crystal otherwise defect centres would cause nonradiative recombination, therefore the lattice constant of the passive layers must be the same as that of the active layer.

As well as carrier confinement the passive layers produce optical confinement because their refractive index is lower than that of GaAs (cf fibres). Figure 2a shows a typical laser structure. Both carriers and light are confined vertically. For lasing to occur there must be confinement horizontally and longitudinally (into the page). The latter is achieved by cleaving the semiconductor along a crystal plane so that there are two parallel perfect crystal planes exposed. The cleaved facets act as mirrors, reflecting 30% of light at normal incidence back into the semiconductor. Horizontal confinement is achieved in figure 2a by cutting a window in an isolating oxide layer. Contact metallisation is then evaporated over the whole top surface but current is confined to flow through the window. This provides some current confinement but no optical confinement. In figure 2b the buried heterostructure laser, better current and optical confinement are achieved by the lower refractive index cladding layers. To make such lasers, layers have to be grown, etched and regrown. It is therefore harder to make such devices free of defects.

Lasing occurs when the optical gain g in the cavity equals the losses due to absorption, scattering and poor confinement α and transmission through the facets. The increase in number of photons (dN) in going a distance dx is given by

$$dN \propto N(g - \alpha)dx$$

So, by integrating,

$$N \propto \exp(g - \alpha)x$$

In one round trip of the cavity, the net gain G will be

$$G = R_1 R_2 \exp[(g - \alpha)2L]$$

where L is the cavity length and R_1 and R_2 are the mirror reflectivities. The condition $G \geqslant 1$ must be satisfied for lasing which is equivalent to

$$\ln R_1 R_2 + (g - \alpha)2L \geqslant 0$$

The value of current for which this occurs is known as the threshold current. Typical light output–current

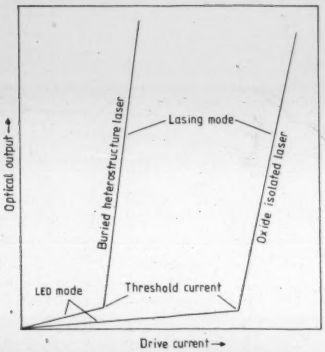

Figure 3 Typical light output–current characteristics for a buried heterostructure and an oxide isolated laser

characteristics for the lasers in figure 2 are shown in figure 3. The oxide isolated laser has a much higher threshold current because of its lack of horizontal optical confinement. The simpler structure, however, may be favoured if it better satisfies another criterion, that of high reliability. Reliability is obviously critical, because of the high costs of maintenance particularly for submarine systems.

So far the discussion of laser properties has centred on the GaAs–GaAlAs laser emitting at 0.85 μm. As fibre losses at 1.3 and 1.55 μm were reduced, new laser materials were researched. The quaternary compounds of In, Ga, As and P were found suitable. By varying the concentrations of component elements, lattice constant and bandgap can be varied independently.

Laser structures the same as for GaAs may be grown and similar light output–current characteristics obtained. These devices have a strong dependence of threshold current on temperature. Designs which reduce the threshold current (and so the power consumption) such as the buried heterostructure are therefore favoured. The reliability, however, of these devices appears to be less of a problem than for GaAs lasers.

Light emitting diodes

Two different structures of LED are commonly made, the edge-emitting LED or ELED, and the surface emitting LED (see figure 4a, b). The former structure resembles a stripe laser where the stripe only runs part of the length. This suppresses lasing, but does mean there is some optical gain for photons produced well away from the facet. The spectral width is therefore less than that of an ordinary LED (less fibre dispersion)

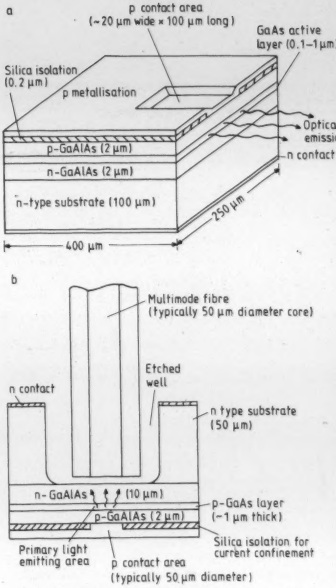

Figure 4 **a,** Structure of an edge-emitting LED and **b,** structure of a surface-emitting LED

but greater than that of a laser.

Surface emitting LEDs are double heterostructure devices also, but the light is emitted in a direction normal to the layers (figure 4b) through a circular well etched in the substrate. A fibre can either sit in the well or a hemispherical lens may be fitted to collimate the light beam. One limitation of such devices is the amount of power which can be coupled into a fibre because of the large source dimension, typically ~50 μm diameter, and large angular distribution of light. These devices are predominantly used in medium bit-rate short systems where device cost is important. Their cost can be as little as around one-fifth that of a laser.

Advanced structures and integrated optics

To improve system efficiency, research continues on designing lasers with lower threshold currents and smaller beam diameters or less divergence to improve fibre coupling. By analogy with integrated circuits, the next level of sophistication is to integrate several optical components on to one substrate. One example is an external laser modulator. If such a device is on

the same substrate as a laser, there is no difficulty in aligning the structures. In all such cases the output facet of the laser cannot be cleaved and the alternative, chemical etching down to the substrate, does not produce such a good quality facet. The facet can be dispensed with if a Bragg reflector is used instead. This takes the form of a periodic variation in the thickness of the active layer; it is a grating and operates in exactly the same way as x-ray reflection by crystal planes. Reflection occurs when

$$n\lambda = 2d\sin\theta$$

In this case n is an integer, λ is the wavelength of the light in the semiconductor, d is the wavelength of the thickness variation and $\theta = 90°$ (normal incidence). This creates the necessary reflection for lasing within a very narrow bandwith (< 1 nm).

A device which makes use of coupling between guided waves is the directional coupler. By analogy to a fibre, the rib structures shown in figure 5 will form waveguides with the following property. A coherent light wave launched into one rib will, at a certain distance, appear in the other. The same distance further on it will have transferred back. Mathematically, there is a superposition of two normal modes propagating; one symmetric, the other antisymmetric (see figure 5). These have different group velocities and hence adding and cancelling occurs at specific distances down the ribs. An electric field applied across each rib can change the refractive index and so the interaction length, via the electro-optic effect. Such a device therefore operates as an optical switch.

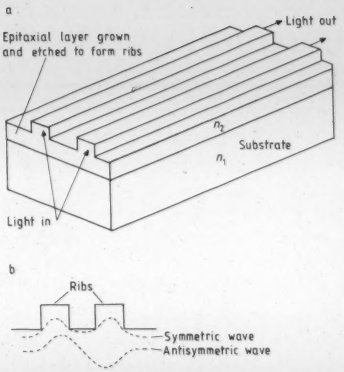

Figure 5 a, Schematic diagram of a directional coupler, with **b,** symmetric and antisymmetric modes which propagate down the rib waveguides. Refractive index $n_2 > n_1$

Photodetectors

A photodiode is basically an LED working in reverse. When a photon is absorbed, it excites an electron from valence to conduction band. If there is a pn junction in the vicinity, the electron will be accelerated to the n-side and its corresponding hole to the p-side, causing an electric current to flow. The devices used in optical systems are designed to have a fast response, low capacitance and low noise. PIN photodiodes and avalanche photodiodes are suitable (see figure 6). The thick low-doped i-region ensures a low capacitance and by applying a reverse bias of ~ 20 V, a response time of ~ 1 ns may be achieved. The i-region also ensures that the dark current (a source of noise) is low, $\sim 10^{-11}$ A.

In an avalanche photodiode the pn junction is narrow, and a high reverse bias field (just less than that required for breakdown) is applied. A photon entering this device creates an electron–hole pair in the high field region; the electron and hole are swept apart and accelerated. They acquire sufficient kinetic energy to create additional electron–hole pairs through inelastic collisions. Using this multiplication mechanism gains of $\sim 10^3$ may be achieved. The APD may provide gain with a low noise penalty under certain conditions. This reduces the additional

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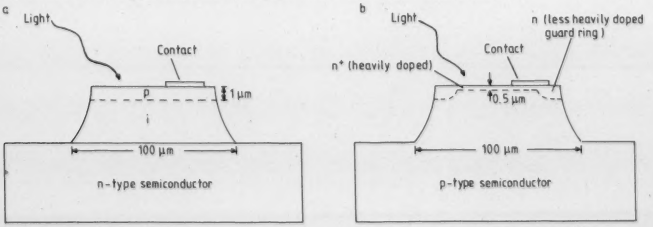
Figure 6 a, Structure of a PIN photodiode and **b,** structure of an avalanche photodiode (APD)



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NOTES ON EXPERIMENTS

'Notes on experiments' enables teachers at both sixth-form and tertiary level to share their ideas with other readers. *Physics Education* welcomes submissions from readers who know of some simple improvement to a commercially made piece of apparatus, or who have designed a new gadget or improved a standard experiment. In particular the Editor would welcome brief descriptions of experiments devised or procedures evolved during the course of project work or investigation undertaken by students; such submissions should be made under the joint name of the teacher and the student.

DEMONSTRATION LAMP BOARD FOR AIRTRACK EXPERIMENTS

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Airtrack experiments are commonly used in teaching Newtonian mechanics in physics courses. However the demonstrational value of these experiments is limited because no suitable display system exists. Some systems, such as light gates, can only measure the velocity at one place and do not give a general view; other systems, such as spark tapes, give a survey over the whole trajectory but can be analysed by only a few students at the same time and mostly with a time lag between experiment and analysis. All the systems used so far present difficulties in demonstrating collision phenomena. In this note a display system is described which can easily be constructed and which gives direct results by marking the positions of airtrack pucks on a measuring board. The marking is done by small incandescent lamps so that it is visible to a large group of students.

The display system consists of a measuring board which can be placed alongside an airtrack. At each scale division (1 cm) a small incandescent lamp (Philips 6 V, 50 mA) and a photodiode (MEL 11) are inserted. Each photodiode is connected to the corresponding lamp by a small electronic circuit, as shown in figure 1. Clock pulses are supplied to the circuit, and can be taken from a function generator whose frequency range covers 1–10 Hz. (The duty cycle of the pulses should be made less than 10%. Figure 2 shows a circuit diagram for an appropriate clock pulse generator.) The circuit of figure 1 switches on the lamp when a clock pulse coincides with a dark state of the photodiode.

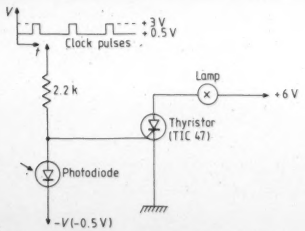
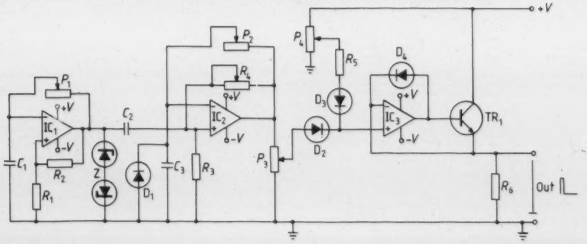


Figure 1 Circuit diagram for display system

To mark the position of a puck a small flag is placed on top of it. When the puck moves along the airtrack the flag eclipses the photodiodes on the measuring board. Every time a clock pulse arrives the lamp corresponding to the eclipsed diode is switched on. Figure 3 shows an example of the marked passage of a puck. Reset of the lamps can be done by interrupting the +6 V power supply (see figure 1).

Figure 4 shows the mounting of the lamps and photodiodes in some detail. As can be seen double rows of lamps and diodes are mounted. (The lower row of lamps is covered with a transparent strip of

Figure 2 Circuit diagram for clock pulse generator. V,15 V; P_1(frequency), 100 kΩ; P_2(duty cycle), 10 kΩ; P_3(amplitude), 20 kΩ; P_4(d.c. offset), 22 kΩ; C_1,C_3, 1 μF; C_2, 10 nF; D_1, D_2, D_4, 1N4005; D_3, 1N4448; Z(Zener diode), 5 V; R_1, 100 kΩ; R_2, 20 kΩ; R_3, R_5, 12 kΩ; R_4(trimpot), 100 kΩ; R_6, 220 Ω; TR_1,BD437; IC_1, IC_2, IC_3, op. amp. 741



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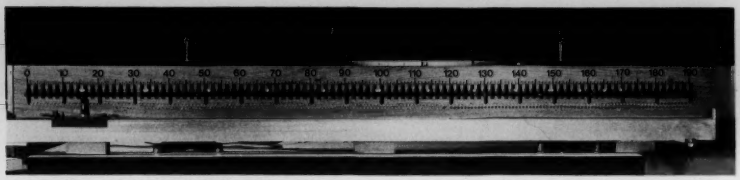
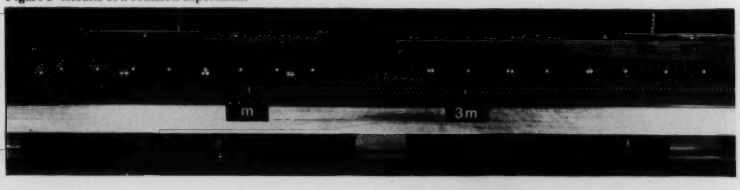


Figure 3 Display of moving puck with position markings

Figure 5 Results of a collision experiment



coloured plastic.) The use of double rows of lamps and diodes makes it possible to demonstrate collision phenomena such as energy relation in elastic or inelastic collisions and conservation of impulse. Indeed the position (and by this the velocity, the impulse and the energy) of the colliding pucks can be distinctively marked before and after the collision. This is done by supplying the clock pulses to one row and switching to the other at the moment the collision takes place. To make the distinction clear different colours can be used by covering the lamps with strips of transparent coloured plastic (as is done for the lower row of lamps in figure 4).

Some examples now follow of experimental results as they are obtained by this method.

(1) Figure 5 shows the result of a collision experiment according to

The lower lamps indicate the velocity of mass m before the collision (mass $3m$ was at rest); the upper lamps indicate the velocities of the masses after the collision took place. The reader should realise that two important characteristics of this demonstration experiment cannot be shown in this note: (a) the real time situation in which students see how the collision takes place; and (b) the colour difference of the lamps. We used three different colours: red for the lower row of lamps, green for the right half of the upper row (positions of mass $3m$ after the collision) and white (bare lamps) for the left half of the upper row. When the marking is done with coloured lamps, the relation

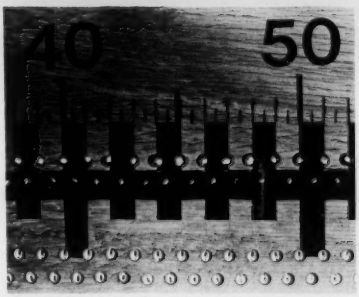


Figure 4 Close-up view of mounting lamps and photodiodes

between the velocities can easily be determined from the display board, leading to an immediate discussion about the impulses and the energies.

(2) From the position and time marked on the display board other functions can be derived: the velocity and the acceleration as functions of time and also the velocity and the acceleration as functions of position. This allows, among other things, the demonstration of conversion of energy when a conservative force is acting on a puck. Figure 6 gives an example of such experiments. The measuring points correspond with the marking data of figure 3 and represent a motion under the influence of an elongated spring. Figure 6b shows that the acceleration is not constant but decreases with increasing time, i.e. when the elongation of the spring

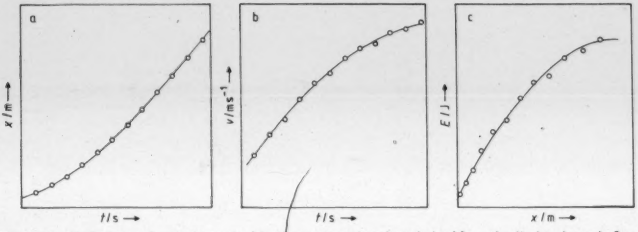


Figure 6 Plots of **a**, displacement; **b**, velocity; and **c**, kinetic energy against time, derived from the display shown in figure

becomes less. Figure 6c shows the parabolic dependence of the kinetic energy as a function of position.

(3) As a last example we mention an experiment in which the conservation of impulse of an isolated system of masses is demonstrated in a fascinating way. Two airtrack pucks are connected to each other by means of a spring. When this system is launched along the airtrack it appears to move in an intricate way. If a flag is placed at one of the two pucks an irregular marking pattern is formed. By placing the flag at the centre of mass, a perfect regular pattern results, indicating that the velocity of the centre of mass remains constant.

A POOR-QUALITY AMPLIFIER FOR EMPHASISING THE BENEFITS OF NEGATIVE FEEDBACK

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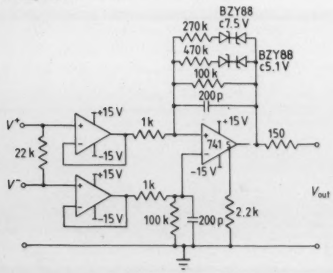
When negative feedback is added to an amplifier, many properties are improved, principally bandwidth, linearity, phase distortion and input and output impedance, at the expense of gain. Other properties such as input bias current and input offset voltage are not affected. In principle it is easy to demonstrate this improvement, but there are some practical problems. In order to show an obvious improvement it is necessary to start with an amplifier with a rather poor performance; a 741 type integrated circuit amplifier for example has such a good performance in many respects that it is difficult to demonstrate an improvement when external negative feedback is added, unless quite sophisticated measuring instruments are used.

An alternative approach would be to use an amplifier built from a few discrete components, and it is quite possible to produce a circuit with an obviously nonlinear response in this way, but it will also show d.c. instability, and this d.c. drift makes it difficult to measure the amplifier characteristics reliably. If internal negative feedback is added to improve the d.c. stability, the linearity is improved until it is too good for our purpose!

Figure 1 Circuit diagram for spoiling some characteristics of 741 amplifier



The approach which we use for our teaching laboratories begins with a 741 type amplifier and deliberately spoils some of the characteristics in a controlled way. This is done so that measurements are reasonably easy to make with normal laboratory equipment and a significant improvement can be demonstrated when negative feedback is added. The circuit diagram (figure 1) shows an amplifier which satisfies these requirements.

A 741 amplifier is wired as a differential input amplifier with a gain of about 100. The input resistances are low and unbalanced, and so two further 741 type amplifiers are used as unity-gain

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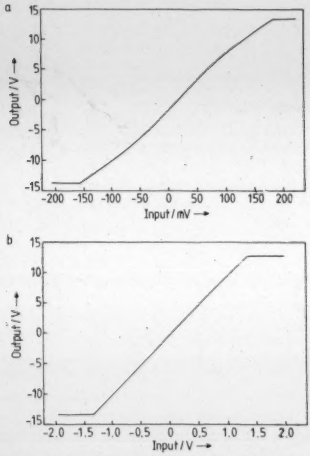

Figure 2 Amplifier characteristics: **a**, without feedback; **b**, with feedback

buffers to increase the input resistance. A 22 kΩ resistor fixes the input resistance, and a 150 Ω resistor the output resistance. Linearity is spoiled by four Zener diodes in the feedback network, which change the gain of the amplifier at four points on the input–output characteristics, at about ±5.5 V and ±8 V. The bandwidth is restricted to about 5 kHz by the 200 pF capacitors, which give a good approximation to single-pole behaviour. These characteristics are virtually independent of the performance of the 741 amplifiers themselves, being set by passive components. Therefore they are constant, and although their values have been chosen for convenience of measurement with typical laboratory equipment, they can easily be changed if necessary.

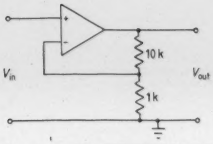

Figure 3 Amplifier with negative feedback

The input bias current is typically a fraction of a microamp, and the input offset voltage is set at about 15 mV by tying pin 1 or pin 5 on the single 741 (DIL eight-pin package) to ground through a 2.2 kΩ resistor, thus increasing the offset null at the 741 input.

Nonlinearity can be demonstrated most easily on an *XY* oscilloscope display or an *XY* recorder (figure 2). If an oscilloscope is used the input frequency should be set at about 25 Hz— high enough to avoid flicker, but low enough to avoid amplifier phase-shift. A d.c. input setting should be used to avoid differential phase-shifts in the oscilloscope input circuit at low frequency.

The linearity, bandwidth and input and output resistances should be improved by a factor of $1 + \beta A_0$ when series voltage negative feedback is added, where β is the feedback fraction and A_0 the open loop gain for small signals. In order to avoid excessive loading effects, the circuit shown in figure 3 is used, for which $\beta = 1/11$, and hence the gain with feedback is about 10, with $A_0 = 100$.

Several of these units have been used regularly over a period of three years and have been very reliable, probably because of the comprehensive protection built into the 741 amplifier. The units are built on small pieces of vero-board, using a 16 pin DIL socket for the amplifiers, and housed in octal-based plastic plug-in boxes. Shielding is not necessary, and any convenient metal, plastic or wooden box could be used. The total cost of the components, excluding the box, would be about £2.

SCHOOL HOLOGRAMS

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South London Science Centre

In this note a simple technique for producing holograms is described which requires no special optical components and which uses a 1 mW school laser. The technique was developed by Bob Waterman and the author at South London Science Centre and the original conception owes much to an article by Graham (1978). The technique was demonstrated at the members' exhibition of an ASE annual meeting, and a short account appeared in *Scientific American* (Walker 1980).

The laser is mounted on a camera tripod pointing vertically down on to a bead of clean mercury of about 1.8 mm diameter. The object, e.g. a toy animal or soldier, is placed close by. The film is placed in a cylinder (or part cylinder) of about 7 cm diameter around the bead and the object (figure 1a). The bead acts as a very short focal length diverging mirror illuminating both the object and the film, and forms a perfect optical surface. The scattered light from the object interferes with the direct light falling on the

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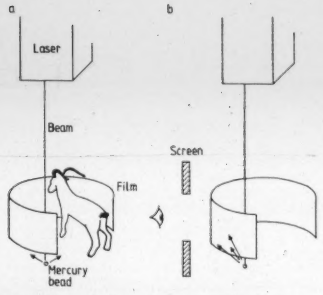

Figure 1 Schematic diagram of **a**, construction and **b**, reconstruction of hologram

film (equivalent to the reference beam in holography) to generate the hologram. A short exposure captures the interference pattern. Any dust on the mercury impairs the result.

Reconstruction of the image is likewise simple (figure 1b). Basically the developed film is placed in roughly the same position with respect to the mercury mirror, and the monochromatic light from the laser is diffracted by the interference pattern on the film to reconstruct the original object.

There is no major safety problem provided that the nature of the hazard is appreciated and appropriate precautions are taken. Reflected light from the mirror should not be allowed to enter the eye directly if the power at the eye exceeds 1 $\mu W\,cm^{-2}$. The laser beam diameter (2 mm) at an assumed maximum power of 1 mW and the mirror diameter determine approximately the angle of the cone of reflected light, and hence the power density at any given distance, assuming 1 mW in the cone. A useful check of cone angle can be made by placing a cylinder of tracing paper over the mercury bead. A simple precaution is to arrange that the observer is shielded from direct light from the mirror and can only observe the image formed by the diffracted light.

Mercury vapour is, of course, also a hazard and appropriate precautions should be taken in using it. It is suggested that (a) a small stoppered bottle of clean mercury is allocated for holograms; (b) a small stoppered bottle is used to store all discarded drops after use; (c) a small fine pipette is used to extract mercury from (a) and make the drops; (d) a coarse pipette is used to retrieve drops after use and to place in (b); (e) drops should not be left exposed when not required and the site of any experiment should be closely and carefully inspected afterwards to ensure that no mercury remains.

The image can be made brighter by using a slightly larger diameter mercury bead for reconstruction, thus illuminating a smaller area of the film with the same light power. (A very large bead resembles a plane surface, however, and the hazard is then comparable with looking directly down the laser beam.) Recognisable, though faint, holograms can be seen without a mirror by using scattered light. The mirror is replaced with a white scattering object, e.g. paper or white plasticene. Thus, the scattered light comes from a near point source. Best results are seen if the object is set at an angle, illuminating the film but leaving the background in the dark. There is no hazard unless very close viewing is possible. Nevertheless, the best contrast is obtained by screening the white object from the eye.

Perhaps the most interesting reconstruction from an educational point of view is by the use of a white light source. The simplest and brightest approximation to a point source is a small torch bulb

Figure 2 Photograph of object (toy goat) alongside hologram. It is interesting to note that the image is in focus, but the aperture and film are not. It is possible to emphasise the three-dimensional aspect of the hologram by rotating the cylinder: the goat can be viewed from the head, side or tail view

Figure 3 Hologram taken with unmounted film using procedure described by Graham (1978). A small obstruction in front of the mercury bead cast a shadow on the film to avoid dazzle. (The dice on the right were not orientated as in the hologram when the photograph was taken)

filament. A prefocus bulb viewed from the side, the lens being blackened, is satisfactory. The image formed is very blurred, with rainbow coloured edges, e.g. a four legged toy appears as a white smudge with coloured legs and edges. However, the three-dimensional effect is clearly observable. A red filter brings a considerably improved image which is easily recognisable.

We have produced the holograms using a 1 mW He–Ne laser (from Griffin and George Ltd or Philip Harris Ltd) fitted with a camera shutter from a scrap camera. We have used Agfa-Gevaert 10E75 film (31 m of 35 mm film costs roughly £37) and Agfa G3P developer (10 l costs roughly £3), both of which are available from Agfa-Gevaert NDT Sales Department, 27 Great West Road, Brentford, Middlesex TW8 9AX. The film is supported on the inside of 7 cm diameter plastic drainpipe, from which a suitable aperture can be cut for viewing. Typical conditions are an exposure of 0.3 s, with 5 min developing time and 5 min fixing.

The following precautions should be taken to ensure good results:

(1) Test lengths of films should be cut off in a darkroom and stored in a light-tight box.

(2) Tests should preferably be taken with the laser tripod on the darkroom floor—a concrete floor at ground level is best.

(3) The size of the mercury bead and the point of incidence of the beam should be adjusted so that the scattered and reference light are of comparable intensity. The emulsion side of the film should face the source. Movement of the film during exposure should be prevented (e.g. by curling the film inside the drainpipe).

(4) A wide range of exposures should be tried until some darkening of the film is achieved without complete blackening. The more light, the shorter the exposure and the greater the chance of a successful hologram.

Finally—although nothing to do with holograms—we discovered a fun phenomenon while attempting to clean the mercury. A mercury drop is placed in a watch glass and a few drops of alcohol are added. A cylinder of tracing paper is placed over the glass as a translucent screen (as mentioned earlier) and the laser directed vertically on to the mercury. As the spirit evaporates, fascinating interference patterns appear on the screen in constant motion. A draught of air speeds evaporation. The interference is dependent on the thickness of the spirit film over the mercury.

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Walker J 1980 *Sci. Am.* **242** 124–6

SINGLE-BEAM HOLOGRAPHIC INTERFEROMETRY FOR TRANSLATION

YEU P HWU

Wytheville Community College, Virginia, USA

In order to give students some feeling for holographic interferometry, a single-beam holographic technique (Jeong 1980) has been used to study the in-plane translation of an object (Hwu 1981). This note describes, theoretically and experimentally, the application of the single-beam holographic technique to an object translated in a plane perpendicular to its surface plane.

The object is a 1.3 cm × 1.3 cm × 10.2 cm rectangular metal rod with one surface polished with sand paper. The rod is placed on the platform of a microscope with the polished surface up. The platform can be raised or lowered by means of a scaled handle. The film is placed such that its plane is perpendicular to the plane of the polished surface of the object (figure 1). The film is exposed. The object is then raised or lowered and the film exposed again.

If we assume a linear recording the irradiance distribution that is recorded on the film can be written as

$$f(x,y) = g(x,y) + g(x-\xi,y) \quad ,$$

Figure 1 Experimental set-up

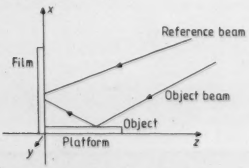
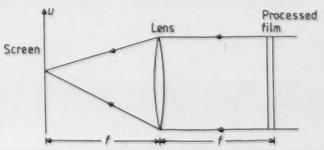


Figure 2 Production of real image from processed film



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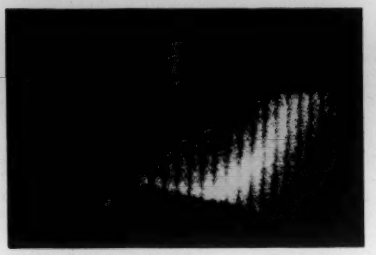

Figure 3 Fringes seen on screen

where $g(x,y)$ is the irradiance distribution from the first exposure and ξ is the displacement of the object along the x axis between the two exposures. This can be rewritten as

$$f(x,y) = g(x,y)^* [\delta(x,y) + \delta(x-\xi,y)]$$

where the symbol * denotes a convolution (Collier *et al* 1971), and $\delta(x,y)$ is a delta function.

The virtual image on the processed film can be seen through the regular reconstruction process; however, if the processed film is illuminated by a parallel laser beam, the real image can be projected and focused on a screen through a lens (figure 2). The amplitude in the farfield (screen) is given by the Fourier transform of $f(x,y)$

$$F(u,v) = G(u,v) [1 + \exp(iu\xi)]$$

where $G(u,v)$ is the Fourier transform of $g(x,y)$. The irradiance on the screen is then

$$A(u,v) = |F(u,v)|^2 = 2|G(u,v)|^2 (1 + \cos u\xi)$$

The irradiance on the screen will have zero value when

$$u\xi = (2n + 1)\pi \qquad n = 0,1,2 \ldots$$

Therefore, the irradiance distribution on the screen is modulated by a system of fringes (figure 3). The number of fringes is proportional to the movement so this process offers a method of measurement of a small displacement.

The set-up is placed on the floor, eliminating the need for a vibration-free table. The procedure is simple, and can be completed within an hour.

I wish to thank Professor Brian J Thompson for his valuable comments on the manuscript.

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A new laboratory course for physics students

A Bonet, L S Quindos, J Soto and E Villar

Since 1977 we have been developing a new laboratory course in mechanics for second-year students in the Department of Fundamental Physics at the University of Santander. The aim has been to increase the students' participation in the laboratory classes and through this we have seen an improvement in the students' approach to the exercises and in their comprehension of the physics. The course is one of four taken by the students in their second year, and occupies 60 hours over a four-week period.

The course had previously been based on a simple instruction sheet, essentially containing the following parts: classification and identification of the necessary material for doing the practical; theoretical background of the phenomenon under investigation; and presentation of the results. Inquiries made among the students showed that few of them felt that the exercises were of value. Consequently we experimented with a new idea for the 1977–8 course, which we continued testing during the 1978–9 and 1979–80 courses.

The new course consists of three main parts: self-evaluation, analysis of the practical, and discussion of results. In the first part the student must answer easy questions related to the natural phenomenon exhibited in the laboratory exercise. The purpose of the questions is twofold:

(1) From the student's answers the tutor discovers possible gaps or misconceptions in the student's understanding of the topic.

(2) The student is able to make his own evaluation of what he knows about the topic.

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The second part, analysis of the practical, involves a series of questions of increasing difficulty, which requires the student to search the literature to solve them. Whilst he is doing this, the student is setting up the theory of the phenomenon that he is investigating and is finding the laws which govern it and their range of validity. This series of questions needs to be carefully prepared so that the student will understand the aims of the exercise and how they are to be achieved with the apparatus provided. Continuing along this line, we hope to find an ideal sequence of questions based on our experience and the critical opinion of our students.

The presentation of results is not the end, but merely another stage in the course. Of greater importance than the practical work is the discussion of the results. This discussion includes answering questions about the experiment, and having the tutor and student examine the difficulties in performing the exercise.

In view of the good response that we have received from students we are encouraged to develop new exercises following the method described here. A description of one of the current exercises follows.

Example of a practical exercise

Objective: Determination of the coefficient of viscosity of a liquid using Stokes' law.

Material needed: Two test tubes, 50 and 100 cm long, with the same inside radius; eight steel spheres; glycerine and car oil; barometer, thermometer, micrometer and ruler.

Self-evaluation:

(1) Use dimensional anaylsis to establish the expression for the upthrust on a sphere immersed in a liquid.

(2) Are density and specific gravity the same? What is the difference?

(3) What do you understand by viscosity?

(4) What is the value of the upthrust on a sphere of radius r immersed in a liquid of density d?

Analysis of the practical

(1) Use dimensional analysis to establish a formula for the frictional force acting on a sphere (of radius r and mass m), falling through a liquid, knowing that this force depends on (a) the coefficient of viscosity of the liquid, (b) the radius of the sphere, (c) the speed with which the sphere falls through the liquid.

(2) Draw a diagram showing the forces acting on the sphere as it falls through the liquid, and write down an expression for the resultant force F.

(3) If we assume that there is equilibrium when $F = 0$, what is the resultant expression for the speed of fall, which we call the terminal velocity?

(4) Are we able to measure the terminal velocity with the instruments available? How?

(5) At this point you should be able to write in a few sentences how you will determine experimentally the coefficient of viscosity. You should show this to your tutor. If you are not sure, you must start again from the beginning.

Discussion of results

(1) If we assume that the resultant force F is zero and use the basic equation of motion we find an expression for the speed

$$v = v_{\text{limit}} [1 - \exp(-\alpha t)]$$

where $\alpha = 6\pi\mu r$, with μ representing the specific coefficient of viscosity and r the radius of the sphere. How is the above expression obtained?

(2) Do you think that the liquid viscosity depends on the temperature? Why?

(3) How do the coefficients of viscosity change when doing the experiment, first in the 50 cm test-tube, then in the 100 cm one?

(4) Do you know of any other methods of measuring the coefficient of viscosity?

continued from p37

amplifier gain required and consequently also the noise amplification.

The material used for these devices is silicon at 0.85 μm wavelength (since the photon provides sufficient energy for the momentum change of the electron, the indirect gap presents no disadvantage in this case). At 1.3 and 1.55 μm silicon is transparent and Ge or quaternary In, Ga, As, P compound PIN diodes are necessary.

Conclusion

It is hoped that these basic simple explanations will suffice to stimulate interest in opto-electronics. It is a new field of activity in which this country is in the forefront. Considerable future development is likely and should provide much excitement in research, development and production and in many novel applications.

Acknowledgment

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BOOK REVIEWS

Science in Schools: Which Way Now? Richard Ingle and Arthur Jennings 1981 Windsor: NFER–Nelson 185pp price £5.30

Despite the attractive cover and the come-hither title, my heart sank somewhat at receiving this book, the eighth in the London University Institute of Education Studies in Education series. The pages are fairly densely packed with fairly small print and well dotted with reference numbers (not uncommonly a couple to a sentence). It didn't appear to be a rattling good yarn, and I didn't feel it likely to answer the question in the title. Well, it *doesn't* answer the question in the title. All the same it turns out to be very readable and very thought provoking.

A third of the book is a well developed account of what has happened in (British) school science in the last century or so. We then have about the same proportion spent on current trends and ideas. (Not quite current of course—Nuffield revisions and the ASE consultative document are in; John Lewis's *Science in Society*, the ASE policy statement, Dick West's ASE/Schools Council project, and the potential of micros are not.) The rest of the book is the authors' proposed secondary integrated science core (it is most unintegrated in fact) and various other appendices.

I really listed the major omissions in the last paragraph not as criticism—they are too recent to be included—but as evidence that school science may be in for another developmental leap forward. That being the case, we should all be aware of what has gone before and what is being mooted now. This book tells us all that very nicely, even if it doesn't answer the question in the title! *Eric Deeson*

Advanced Physics S M Geddes 1981 London: Macmillan Education viii + 368pp price £5.95

This book is intended for A-level students who in the authors words are 'aiming for a pass in the examination but probably not intending to proceed further in pure physics'. It is an attempt to achieve a simple nonmathematical approach to the subject. The topics are set out in a somewhat unconventional order which is intended to represent developing complexity. There results a certain lack of continuity in the scientific ideas which many will find unacceptable. A typical example is that alternating current in capacitors is covered before the concept of capacitance is dealt with at all. The atomic physics section is particularly brief and disappointing. It somewhat surprisingly includes a treatment of electric and magnetic fields. There is, in fact, no proper mention of atomic structure and energy levels until much later in the book.

Altogether the author has attempted to write a simplified version of an A-level physics course, by leaving out the excessive and unnecessary details found in all A-level texts. Unfortunately, in doing so, a lot of the required concepts have been omitted or given such scant attention as to be insufficient for syllabus requirements. *J Rielly*

Physics: Foundations and Applications vol. 1 Robert M Eisberg and Lawrence S Lerner 1981 Maidenhead: McGraw-Hill xii + 711pp price £15.50

References to pigskins, baseballs, subways and elevators clearly tag this book for an American audience. It is designed for a first, university-level course for the serious science or engineering student who is at least taking calculus concurrently. The organisation of volume 1 follows a familiar pattern: kinematics, Newton's laws, oscillatory motion, energy, rotational motion, gravitation and waves. The remaining two chapters deal with relativistic kinematics and mechanics. A unique feature makes it well suited for our modern, hand-held calculator age: computer-based mathematical methods such as numerical differentiation/integration, numerical solution of differential equations and curve plotting are introduced and applied. Along with a wide selection of imaginative end-of-chapter exercises (organised by difficulty) are special problems designed for solution on a programmable calculator.

No textbook is perfect for all needs and tastes, however this one has the marks of a potential classic: it is well written and clearly illustrated, the worked examples are logical and thorough, the treatment is rigorous but not pedantic, the mathematical methods sections are novel. This volume will fit nicely beside the senior author's renowned books on modern physics and quantum mechanics. It is certainly worth serious consideration before picking your next course text; a must for your lesson preparation library.

W K Pendleton

Advanced Physics—Fields, Waves and Atoms 2nd edn vii + 552pp price £4.75, **Materials and Mechanics** 2nd edn viii + 374pp price £3.75 Tom Duncan 1981 London: John Murray

The second edition of *Fields* contains much of the original material, but includes a rewritten and considerably extended chapter on electronics. Each of the 12 chapters opens with a resume of the chapter's contents and concludes with a wide range of questions, numerical answers being given at the end of the book. The text is interspersed with a number of photographs, showing pieces of equipment and appli-

cations of principles, and clear and straightforward diagrams. There is a short section of objective questions and 13 brief appendices which include formulae proofs, suggested experimental techniques and electronic circuits.

Materials follows a similar format, and to satisfy the requirements of materials science the materials section has been extended from the first edition. Good use is made throughout of diagrams and photographs. However one or two of the photographs, particularly figures 6.19 and 8.12, were of a poor standard and I would also have liked to see explanatory captions beneath the photographs.

In spite of these criticisms the two volumes will be of considerable benefit to any A-level physics student and are likely to become standard texts for many A-level courses. *Gordon Miller*

Physics for Science and Engineering Dudley Williams and John Spangler 1981 Wokingham: van Nostrand xv + 974pp price £21.20

The first point about this book is that it is a *student* text: there are around 40 problems to each chapter, with answers to the odd numbered ones, besides a dozen or so thought-provoking 'questions'. There is a teasing question on fluid mechanics (p302): '9. A rustic riddle: "Why is it that with a tubful of water on a platform weighing scale the scale reading does not change when a *live* fish is placed in the water?" Beware of riddles that begin with *why*!'. I worry a little whether the average student would take sufficient notice of the caution about riddles.

The book excludes only physics for nonscientists: it assumes numeracy, though the mathematical standard is not demanding—knowledge of calculus is a useful but not essential prerequisite and the use and explanation of vector operations are minimal. The price might deter British students. It is impracticable to produce a book of nearly 1000 pages in paperback, but as the volume is divided into six parts, covering mechanics, heat and thermodynamics, wave motion and sound, electromagnetism, light and modern physics, there might be a case for offering it on the British market as a set of paperbacks. This would have the further advantage of enabling a teacher to recommend to students those parts with which he or she is particularly in sympathy. This reviewer, for example, would not use part 4 on electromagnetism. The controversy between engineers and physicists over D and E, B and H, is avoided by not mentioning D, Gauss's theorem being quoted as $\oint\oint E \mathrm{d}S = Q/\varepsilon_0$, while magnetomotive force is not mentioned in the text although it appears in one of the tables of conversion factors. However, others may welcome a radical approach which is untainted by engineering practice.

This is an interesting book which makes a mainly successful attempt at a step-by-step presentation of the whole span of physics, at a standard between A-level and first-year university, which a competent and conscientious student could not fail to follow.

D A Bell

Wykeham Science Series

The Architecture of Solids (no. 58) G E Bacon 1981 Basingstoke: Taylor and Francis viii + 140pp price £5.50

The term 'architecture of solids' may be a rather unfamiliar one, but it describes quite well the topics covered by the book and the approach adopted by the author. The book consists of nine chapters covering crystal form and habit, physical properties of crystals, the internal structure of crystals, structural arrangements, types of bonding, types of structure, disorder and defects, and magnetic structure. The final chapter is a one-page summary. There is also a glossary and a short bibliography. The text is well illustrated with clear line diagrams.

As with others in the Wykeham Series this book is pitched at about first-year university level. A lot of ground is covered reasonably comprehensively despite the fact that little previous knowledge is assumed. The emphasis is on a descriptive approach with the very minimum of mathematics. It forms a good introduction to the solid state and provides a sound, up to date basis for the further, more detailed study of the relationship between structure and properties that the student is likely to meet later in his or her university course. *J A Champion*

Secondary Science Series

Projects in Chemistry R H Stone and D W H Tripp 106pp, **Projects in Biology** E J Ewington and J Spencer 106pp, **Projects in General Science** R S Wood 118pp, **Projects in Physics** L J Campbell and R J Carlton 116pp 1981 London: Routledge and Kegan Paul price £4.95 each

This series of books is rather like a junior *Flying Circus of Physics*, but applied in a practical sense to all the main areas of school science up to O and CSE level. Each book contains of the order of thirty projects with titles of the form 'What makes . . . ?, How does . . . ?, How can . . . ?, Which is best?, Why are there . . . ?, What happens if . . . ?'. Very clear instructions are given for the initial parts of each project, the equipment needed, how to make any unusual items, safety precautions and hints of what to look for. However, each project has a 'Go on from here' section which suggests further studies on the same theme.

I would see these books of great value in all courses, providing opportunities for guided

investigation at a range of levels from low CSE to the highest grade O-level. There are even possibilities here of extensions into A-level work. Certainly an invaluable aid and highly recommended for purchase.

Chris A Butlin

Cosmic Discovery—The Search, Scope and Heritage of Astronomy Martin Harwit 1981 Brighton: Harvester Press xi + 334pp price £12.95

What a delightfully surprising book. I picked it up prepared for yet another popular account of 'Life, the universe and everything' and found instead that Martin Harwit had written a most thoughtful analysis of the development of astronomy and in particular how major phenomena came to be discovered, by whom the discoveries were made, what training and preparation the discoverers had received and what methods they had used. But this is not simply a historical exercise; armed with his studies of the past he sets out to examine the scope of future astronomical discovery and asks how can we plan future enterprises to make them more effective than past efforts. Nor is he content to simply pose the questions; Harwit argues persuasively for the need for enlightened planning and concludes with 13 specific recommendations aimed at producing a healthy future for astronomy. I cannot resist quoting the first of these: 'As a first step towards attracting a younger generation of astronomers competent to make major discoveries, we should make sure that our best students of astronomy are trained in physics as thoroughly as the physicists themselves'. I shall not argue with Fred Hoyle: 'A remarkable book . . . deserves to be a great success'.

J M Irvine

Conceptions of Ether—Studies in the History of Ether Theories 1740–1900 G N Cantor and M J S Hodge (eds) 1981 Cambridge: Cambridge University Press x + 351pp price £30

Here is a series of contributions about ether and its conceptual development and diversity over the years 1740–1900, which illuminate the Newtonian influence and proceed to Maxwell and beyond. As devices which have bedevilled science for centuries long before the time span considered, ethers have invariably been erected, resurrected or structured to suit the vagaries of influential opinion—not always scientific. In this work details of such attitudes and beliefs are revealed so that, while one author treats ether in philosophical vein, another in theological context and yet others from the chemical, physiological or electrical viewpoints, essentially this is a book that encapsulates the 'spirit of ether'. Ultimately a source book for the science historian, it is notably academic and seems certain to add its weighty contribution to the library shelf.

Joan L Hawes

FORTHCOMING CONFERENCES AND COURSES

Physics of sailing (afternoon) Southampton 20 January Info: The Meetings Officer, The Institute of Physics, 47 Belgrave Square, London SW1X 8QX (tel. 01-235 6111)

16+ biology, chemistry and physics—the present and the future (evening) Preston 28 January Info: Dr C J Walton, W R Tuson College, Preston (tel. 0772 716511 ext. 243)

Radiological health and safety for radiological protection supervisors (sealed sources) Kingston upon Thames 1–5 February Info: School of Chemical and Physical Sciences, Kingston Polytechnic, Penrhyn Road, Kingston upon Thames, Surrey KT1 2EE (tel. 01-549 1366 ext. 312)

The physics of magnetic recording (evening) Birmingham 2 February Info: Mr I F Hunt, Department of Physics, Chancellor's Court, University of Birmingham, PO Box 363, Birmingham B15 2TT

The role of nuclear power in Britain's future energy requirements (evening) Coventry 2 February
Info: Dr G Rowlands, Department of Physics, University of Warwick, Coventry CV4 7AL (tel. 0203 24011 ext. 2384)

What is materials science? (evening) Colchester 4 February Info: Liaison Officer, University of Essex, Wivenhoe Park, Colchester CO4 3SQ (tel. 0206 862286 ext. 2375)

The physics and psychophysics of music (evening) Colchester 10 February Info: Liaison Officer, University of Essex, Wivenhoe Park, Colchester CO4 3SQ (tel. 0206 862286 ext. 2375)

Physics in hi-fi systems (evening) Coventry 2 March
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Properties of matter in simple atomic terms (afternoon) Cardiff 3 March Info: The Meetings Officer, The Institute of Physics, 47 Belgrave Square, London SW1X 8QX (tel. 01-235 6111)

The physics of ball games (evening) Colchester 3 March Info: Liaison Officer, University of Essex, Wivenhoe Park, Colchester CO4 3SQ (tel. 0206 862286 ext. 2375)

Linking experiments to microcomputers (evening) Preston 11 March Info: Dr C J Walton, W R Tuson College, Preston (tel. 0772 716511 ext. 243)

Electronics for teachers Kingston upon Thames 15–19 March Info: School of Chemical and Physical Sciences, Kingston Polytechnic, Penrhyn Road, Kingston upon Thames, Surrey KT1 2EE (tel. 01-549 1366 ext. 312)

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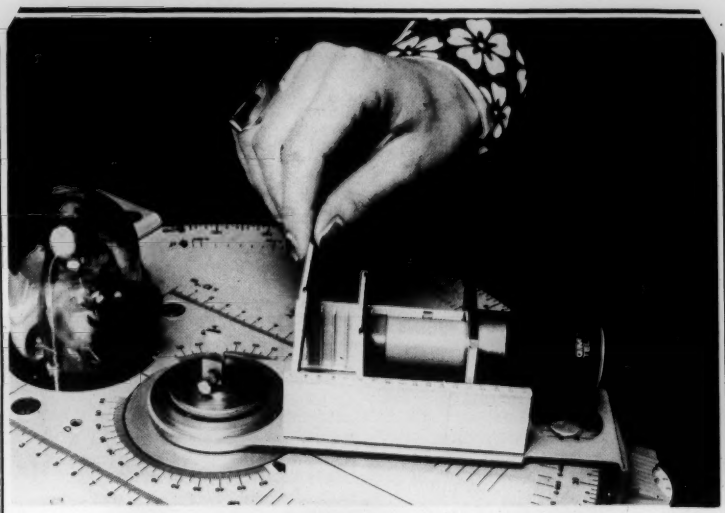

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